EGYPTIAN IRRIGATION

THIRD EDITION

EGYPTIAN IRRIGATION

VOLUME II

EGYPTIAN IRRIGATION

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"O thou River, who did'st bring forth all things,
When the great gods dug thee out,
They set prosperity upon thy banks."
Ancient Babylonian Hymn.

81 Plates and 188 Illustrations

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EGYPTIAN IRRIGATION.

CHAPTER VIII.

DRAINAGE AND LAND RECLAMATION.

PARAGRAPHS 79 to 86 are epitomised from a lecture on *The Drains of Egypt*, given at a meeting of the Khedivial Geographical Society on the 1st February 1913.

79. "**Lower Egypt.**—The lands of *Lower Egypt* may be thus divided:—

(*a*) In the south, the converted basins of the beginning of the nineteenth century, upstream of a line joining Dilingat, Saft-el-Malûk, Damanhur, Teh-el-Barud, Shibrakhêt, Rahmania, Dessuk, Sanhûr-el-Medina, Nashart, Kallin, Simillay, Mehalla-Kobra, Tira, Talkha, Mansura, Simballawein, Safûr, Fakûs, Abu-el-Akhdar, Bordein, and Bilbeis.

(*b*) The deltaic lands to the north of this line.

Beginning at the head of the Delta, the country is absolutely flat, and, as one goes northwards towards the line of towns and villages just given, the valleys between the old canals begin at first to be scarcely visible, while, as one approaches the line, the depressions are more evident, but not more so than in the larger basins of Upper Egypt. North of the line the depressions are more and more marked as one approaches the lakes.

These lands may be further subdivided into the following belts:—

(*a*) South of the line.

(1) 810,000 acres nearest to the apex of the Delta and not needing drainage.

(2) 970,000 acres north of the last, and capable of having their ground water maintained at a sufficiently low level by deep

irrigation canals, and by free flow drainage in the existing drains deepened and kept clear of weeds. These drains would either flow into capacious drains taken down the marked depressions further north, or be led into the Damietta and Rosetta branches and pumped during flood. We have now reached the line of villages already mentioned, and are leaving the closely packed fellahin tracts.

(*b*) North of the line.

(3) 1,320,000 acres of cultivated land needing drainage, generally by pumping. We have now accounted for the 3,100,000 acres of cultivated land in Lower Egypt.

(4) North of these last, and in places mixed with them, are 1,200,000 acres of waste land, ordinarily too salted to produce crops without reclamation works.

(5) Then there are the lakes, covering 660,000 acres.

(6) Between the lakes and the sea are 240,000 acres of sand dunes with the valleys and some large level stretches of land capable of being profitably cultivated.

The total area comes to 5,190,000 acres. We may thus tabulate this information in thousands of acres.

Table 207.—Areas of Belts in Lower Egypt (in thousands of acres).

Locality.	Cultivated Area not needing Drainage.	Cultivated Area needing Deep Canals and Free Flow Drainage.	Cultivated Area needing Drainage.	Waste Lands.	Lakes.	Sand Dunes and Plains.	Total.
East of the Damietta branch . . .	280	410	530	410	410	20	2060
The Delta proper .	490	330	470	470	140	180	2080
West of the Rosetta branch . . .	40	230	320	310	110	40	1050
Total . .	810	970	1320	1190	660	240	5190

We shall consider each of these belts separately.

80. **The cultivated area not needing drainage** lies around the apex of the Delta, and is in great part irrigated by lift in summer. These are the richest lands in the Delta to-day, though, fifteen years ago, they were poorer than the lands in the next belt. Every effort should be made to keep the ground water never less than 2 metres below the ground. In India to-day, if the ground water rises to within a certain distance of the surface of the ground in irrigated tracts, severe restrictions are put on the

irrigation. In Egypt it would be wise indeed to pass a law that in the rich lands in the south of the Delta, if the ground water rises above a certain height, the canals shall be lowered and lift irrigation imposed in summer. The so-called penalty will be a blessing in disguise.

81. **The cultivated area needing deep canals and free flow drainage** was formerly the rich middle belt of Lower Egypt and the crown of the perennial irrigation introduced by Mohamed Ali; and indeed in favoured localities to-day we can still see some of the choice land at its best. High-level canals and an excessive rise of the ground water have, however, shorn this land of its glory. Here it should be possible to deepen existing drains and keep them clear while still few in number; to deepen the main canals; reduce the unnecessary number of regulating works; and, above all, legislate, as proposed in the first belt, for all localities where the ground water is less than 2 metres below the surface of the land. The lands here are capable of producing, when the ground water is low, an absolutely perfect crop of Indian corn in flood with flush irrigation, and a perfect winter crop. A landowner would grow all the cotton he could by lift in summer and then have free flow for maturing his cotton and his Indian corn crop. What hardship is it to a man to pay £2 an acre for his water and then sell £5 or £6 more of cotton per acre? This land is worth saving at all costs.

82. **The cultivated area needing drainage** lies north of the old basins, and the land needs deep 2-metre drainage in the south and shallower drainage in the north. Wherever the ground water is 2 metres and more below the surface, as it used to be in Lower Egypt when the yield of cotton was high in quality and quantity though little trouble was taken to exterminate the cotton worm, the best results are obtained. This applies to the south. Irrigation water goes further; the salts are kept down, and rice is not needed to refresh the soil. Where, however, we approach the lakes, M. Mosséri has demonstrated that the best results are obtained by depths of from $1\frac{1}{4}$ to $1\frac{1}{2}$ metres below the surface. If in the moist tracts, where the ripening of the cotton plant is retarded, the ground water, and with it the salts, are far below the surface, the plants take a development which generally results in a great part of the bolls not being ripe before the winter, and being consequently sacrificed.

These lands were principally reclaimed by the owners of the large estates created by Mohamed Ali; and having slopes towards the depressions, are no longer the table-lands of the south. In favoured localities these lands could be drained by gravitation, but pumping would be generally preferable. The lands find themselves as a rule in this position: high and more or less sandy tracts along the canals running in the beds of the old branches of the river, and dense clays in the depressions between them. Here and there some stupidly aligned canal, like the

Gafaria or Nizam (it was dug by regular soldiers or nizams), runs across the depressions, and is provided with syphons. The depressions are as a rule in Gharbia occupied by drains, and the high lands by canals. The Nashart is an exception. It was an old lying basin escape converted into a splendid escape-drain, and, later on, made into a desperately bad irrigation channel. In Behera the canals are as a rule badly aligned, and the drains have to suit them. Canals and drains run parallel to each other, side by side, and then cross each other in a labyrinthine manner. While Dakhalia and the Bahr el Bakkar section of Sharkia are drained on true principles, the rest of Sharkia is drained on unsound lines. The natural *bahrs*, which ought to be the true irrigation channels of the country, have been converted into drains, while small irrigating canals run on either side of them, because here we have the highest land. Drains run down the depressions, rightly enough, but they are tailed, against the slope, into the *Bahrs*. The *Bahrs* Fakûs and Sân are drains. They should be canals. And indeed, if ever the lands near the lake are to be reclaimed on sound engineering lines, the *Bahrs* will again be converted into canals as they were twenty years ago; and main drainage escapes will occupy the depressions.

To-day in those localities where the canals occupy the high lands and the drains are in the depressions, as they ought to be, this is the state of affairs. The main canals carry high-level water and give flush irrigation by rotation all the year round, as they ought to do. The minor canals take off the main canals and often follow the lines of the old minor branches. Such canals are well placed. They tail into the drains, which are both escapes for the excess water of the canals and for the drainage water. They will in future be called 'escape-drains.' Minor drains running in the secondary depressions between the minor canals also tail into the main escape-drains. Well-treated canals have regulators at their tails which are opened and closed by rotation. Badly-treated canals have earthen banks across their tails. Now, in those seasons of the year when Nile water is clear, there is no object in sending down any discharge in excess of that needed for liberal irrigation and washing; though in winter when rain threatens or falls, the escapes are always needed. At such times all surplus water flows into the main escape-drains through the tail regulators where they exist, or through the drains. Otherwise it is held up in the canal as a high-lying, long, narrow marsh, hurting the land on both sides.

So far the months of clear water. When the Nile comes in flood, the water is laden with rich sediment, which has secured fertility to Egypt for seven thousand years. Now, this sediment can be carried to the fields down the canals only when they run with sufficient velocity. Therefore in flood time, if good, rich, fertilising water for irrigation is wanted, it should be flowing freely into the escape-drain. It was when Colonel Ross saw the restrictions being put on the canals so that the drains should

practically cease to carry escape water in order to give free flow drainage, that he remarked about the lack of red water being the greatest calamity to be dreaded in the Nile Valley. Canals which are not allowed to flow freely, but are strangled, carry little sediment, and become stagnant pools of clear water covered with lotus and dwarf papyrus. The lands on such canals, except near the head, are deprived of red water. If the red water is allowed freely to enter the escape-drains, the quantity of water to be transported increases, the level rises, and the drainage becomes indifferent. To secure good red water in plenty for the fields, and also to drain them deeply and efficiently, there is this solution. Let the main escape-drains run freely into the lakes, carrying the surplus red water of the canals at any convenient level (in Italy some escape-drains run 1½ metres above ground-level in dense clay soils like what we have in our valleys), while the drainage water is pumped into them at convenient places. This is known as *Drainage by Zones.*

The main canals run freely, carrying on the rich red water of the Nile, and the minor canals run freely also. They often tail into the main escape-drains which eventually flow into the lakes. The larger secondary drains, into which also minor canals and large watercourses tail, become escape-drains and flow into the mains. The smaller secondary drains in most places now find that they cannot enter the mains at a sufficiently low level to drain their lands properly. At their tails and along the larger secondary escape-drains and the mains, at suitable places, pumps are placed and the drainage water pumped up into the mains and larger secondaries. Lands located at a high level are drained by free flow, and only such water is pumped as requires to be pumped. The cost of pumping is reduced to a minimum. The lands are drained just as deeply as we want them to be drained, and the rich red water of the Nile flood is secured in abundance. It has been found in Italy with the slopes they have in the delta of the Po that areas under 2500 acres are most effectively and economically drained by single pumps. Such areas would answer in Egypt in the low flat plains in the north, while larger areas, according to available slope, would answer for the south. A pump on the escape-drain, with a syphon under it, would serve 2500 on one side of the drain and 2500 on the other, or 5000 acres in all as a minimum. The maximum for really efficient and economical drainage would be 8000 acres.

83. **The waste lands**, as a rule, are at a lower level than those of the last category and lie immediately to the south of the lakes. They cover some 1,200,000 acres. Of these lands the following appeared in the second edition of *Egyptian Irrigation*:—

'In Ptolemaic and Roman times the whole of this land, known to-day as the *Berea* (plural *Berari*) or waste land, was cultivated. The wilderness bordering the lakes was known later as the *Ard zafran*, or choice land.

According to local tradition, partially confirmed by the presence of Pharaonic summer canals and cyclopean dykes, some of these tracts were once covered with vineyards, while the rest were divided into enormous basins of some 50,000 acres each and planted with wheat. They are credited with having supported a dense population. They are now a barren plain, from which rise numberless mounds strewn with bricks and pottery.

When the lands were under cultivation the sand bars between the sea and lakes must have been pierced by numerous openings, through which the flood waters poured during the yearly inundations. The quantity of water discharged into the lakes on the emptying of the Lower Egypt basins must have been over a hundred times as great as it is now. Owing to these numerous and capacious openings, the lakes were kept on the level of the Mediterranean, and prevented during storms from overflowing the lands to the south by very powerful dykes. Gradually, however, as basin irrigation was abandoned and perennial irrigation introduced, the discharge entering the lakes decreased, and the openings diminished in number and capacity, while now each lake has but one opening, and its area is dependent on the quantity of water which has to force its way through it. If the quantity is large, the opening is wide and deep and cannot be obliterated by the periodically strong north-west winds filling it with sand; if, on the contrary, the discharge is feeble, the opening is insignificant and can be obliterated by sand. If an opening is ever obliterated by sand and the sand well piled up by strong winds, the lake in flood has to rise to a considerable level before it can cut its way through the sand. This rise was so serious in 1890 in Lake Borollos that the water threatened the cultivated lands and the opening had to be artificially begun. As the difference in water-level was great, the opening was soon widened and deepened by the action of the water itself. The capacity of the water for scour depended, however, solely on its head. To keep these openings clear with feeble supplies of water and without permitting the levels of the lake to rise will be a difficult task, and one needing dredging plant.

When we consider that the whole area of land in the Delta which is thoroughly reclaimed is only 2½ million acres, while we have 1½ million acres of land undergoing reclamation and producing feeble crops, or waste, or periodically flooded with salt water—and we know, moreover, that the whole of this land was once well cultivated and densely peopled—we realise what a serious calamity for Egypt was the abandonment of basin irrigation over such areas by the Arabs and Turks. Not only did they allow 40 per cent. of the cultivated land of the Delta to fall out of cultivation, but by keeping it out of cultivation for so many years, they rendered it so salted and barren that its reclamation became an exceedingly difficult problem. Whether this deterioration has been due to the abandonment of basin irrigation alone, or whether it has not been intensified by other factors is open to doubt. There is a tradition that the level of the land itself fell some nine hundred years ago during a severe earthquake.'

In the early days of the Occupation, when the canals tailing into the northern lakes were real canals, the question of utilising all this water running to waste in flood seriously engaged the attention of the officers of the Irrigation Department, and some figures from the appendices printed with the Report for 1886 are given below, to explain how matters then stood.

'In an ordinary flood the following supply was poured into Lake Borollos:—

Bahr Saidi	210 cubic metres per second
Kotoni	10 " " "
Baguria	150 " " "
Kasad	20 " " "
Gafaria	15 " " "
Malha	40 " " "
Tira	15 " " "
Belkas	10 " " "
Total	470 cubic metres per second.

When the Bahr Saidi was closed in 1886, and the Baguria drawn on to do its work, it was estimated that 150 cubic metres per second entered the lake through the canals, in addition to all the drainage water in the escapes.

Before the closing of the Bahr Saidi, the opening into the sea west of Beltim was 100 metres wide, 5 metres deep, with an area of 500 square metres and a discharge of 450 cubic metres per second. After the closing of the Bahr, the opening was 50 metres wide and 1 metre deep. The lake rose in flood generally to a height of 1 metre above sea-level; and then, aided by the local people, cut a passage through the sand bar which formed annually, and soon forced an opening for itself into the Mediterranean.

The Bahr Fakûs at the end of August 1886 was discharging 45 cubic metres per second into Lake Menzala, and the Bahr Moês was discharging some 50. The opening at Gemil between Menzala and the sea was 100 metres wide and fully 5 metres deep.'

The idea in those days was to wash the salted lands by basin irrigation and reclaim them. We overlooked the element of time. A dynasty of Pharaohs would have thought nothing of reclaiming a basin in a hundred years. We tried to do it in a quarter the number of months. On page 55 of the Irrigation Report for 1886 is given a report by one of us, and here is a selection from it:—

'Let the waste land be divided into suitable basins and let the Government inform the fellahin of Menufia, Kaliubia, and Southern Gharbia that if a certain number of them, say twenty-five, will cast the embankments, dig the canals, and complete the work needed for one basin, they may reclaim and cultivate it, and after five years they will become the possessors of 1000 acres, provided they pay the local land tax.

That fellahin from Menufia do not come to the *Berari* now is not to be wondered at, since they are invited to a desolate-looking country to toil and slave the whole year round ploughing and re-ploughing for cotton, or else working at their wheels, and in the end, however hard they work, never to own a single acre of their own but to remain to the end of time hewers of wood and drawers of water to landed proprietors who live in Cairo and Alexandria, or Daira and Domains officials who grow rich while they remain poor. To thoroughly reclaim the *Berari*, the Government must get down the fellah, give him a direct interest in the

land, let him spend all the profits of the land on the land itself and not a hundred miles away from it, allow him to use Nile water when it is valuable, and the Nile itself will reclaim the 300,000 or 400,000 acres of waste land in Gharbia. It must be possible to restore this land to the fertility it once possessed under the Pharaohs, who were acquainted with no arts which we do not possess, but under whom what is now a desert was then a garden, and what are now numberless ruins were populated towns and villages.'

We little realised how difficult it was to reclaim land quickly, and, when reclaimed, to keep up its tilth and fertility. After two years' feeble effort with small driblets of money the project was abandoned; though, if the Treasury had had money, Nubar Pasha would have continued it. Anything new fascinated him. We still believe that if twenty-five years ago we had utilised the red water of the Nile flood, and, instead of losing patience, had continued basin irrigation till to-day, the basins would have been so much improved by this time, aided by a few drains, that we should have had hundreds of thousands of acres of some sort of wheat and barley where we have something to-day which looks like Sodom and Gomorrah after their overthrow. We quote again from the Report of 1886 already mentioned :—

'With a persistency worthy of a better cause, the cultivation of cotton is insisted on, and you see here and there a wretched peasant, with a look of defiance on his face, ploughing up the contracted bed of an old drain or canal in the midst of a vast salt plain. The only remedy for all this is a return to the basin system. It seems ridiculous that during the summer months, when water has no fertilising property and there is very little of it, landowners should go to the very greatest expense to lift it on to a dozen fields from among a thousand. These few fields they have to plough and toil at through the year, and when the flood comes with rich fertilising water in plenty and at a suitable level for irrigation, heaven and earth are moved to keep it within its banks and prevent it from reaching the lands which it irrigated in old times. If it were only allowed to cover the whole thousand fields, it would deposit on them a rich soil, which ordinarily without ploughing and without irrigation, would yield a magnificent crop, a hundredfold more valuable than the sickly cotton and rice now produced.'

Colonel Ross, the first Inspector-General of Irrigation, saw further than any of us and never ceased to deprecate the reduction of the discharges of the canals into the escapes, which was lessening the deposits of rich mud on the fields. This reduction was the consequence of our abandonment of reclamation by basin irrigation, and the desire to make the escapes act both as escapes for the canals and carriers of drainage water by gravitation. The Land Tax adjustment investigations confirmed the truth of these two sayings of two savants: (1) Colonel Ross's saying that 'the greatest calamity which could overtake any part of Egypt would be a red-water famine,' and (2) Dr Schweinfurth's saying that 'perennial irrigation was an unending fight against salt.' A red-water famine could be guarded

against by allowing every canal to carry in flood the maximum quantity of rich red fertilising water it could, and by escaping this water freely into the escapes. Salt could be ensured against by deep drains with their water-surface at a low level. The second edition of this book was written in 1897 to bring this home to the country, and to prophesy what would occur if flush irrigation in summer became general in the higher lands, and if, further down, there was a continued wholesale abandonment of the escape as escapes, and their conversion into drains. Independent drains for drainage and independent escapes for escape water were advocated as alone giving any chance to plentiful supplies of red water and deep drainage by free flow. This was criticised by Sir Hanbury Brown, the Inspector - General, in the preface he kindly wrote for the second edition. His views are given on pages xxiii and xxiv of the preface. He contended that by widening and deepening the escapes and using them as escape-drains, we should be able freely to escape our water, the importance of which he well knew, and at the same time drain our lands by gravitation in one and the same channel. Time has shown that we cannot, and after fifteen years' effort and failure, the Government has decided that the drainage must be pumped in a wholesale manner. Once it has been decided to pump the drainage, Sir Hanbury Brown's ideal state of one single channel carrying both escape and drainage waters can be realised, and we can use one and the same channel by allowing our escape water to enter freely by gravitation and our drainage water by pumping. Here we should have a truly ideal state—rich red water everywhere and low-level drainage.

To divide the districts into zones, and economise capital expenditure and maintenance, and at the same time have perfect irrigation and drainage is the true scientific solution of the problem. It involves having a large number of pumping stations, but a modern pump by a good maker is as safe as a good watch and as easy to keep going. There are thousands of pumps on canals or in the fields, for irrigation purposes, and they never give trouble; while no one has yet put up a pump to lift his drainage who has not found it as easy to manage as it is effective in what it professes to do. There are very many of these pumps now working in Lower Egypt and revolutionising land reclamation.

To avoid the difficulty of working numerous small pumps, though they can be worked by large installations in groups with the aid of electricity, it has been proposed to lift, at one single pumping station at the tails of the main drains, all the drainage water which needs pumping, all the drainage water which could be drained by gravitation, with all the escape waters of the canals not requiring pumping, and representing more than half of the total; and at the same time, to ensure everywhere in every

length of every drain, big and small, over thousands of kilometres, a uniform depth of water of 1·50 metres below the ground.

If in order to obtain free flow drainage, independent of depth below the surface, the Department had to go in for the wholesale reduction of escape water, and then after fifteen years, give it up in despair, what will it have to do now? The tails of the canals will not be controlled by regulators, but will be sealed hermetically, and the rich red water of the Nile flood reduced to an absolute minimum; the inlets into the drains will be reduced and ever reduced to force people to diminish their rice areas which discharge large quantities of water into the drains and which are the lineal descendants of the old basins; the sale of waste land will be discouraged, because the really serious reclamation of these lands will demand both excessive quantities of red water in flood and also of drainage capacity, and both together would drown out the pumps. Lands which might have been reclaimed in a few years with a liberal allowance of rice, red water, and deep drainage will eke out their reclamation; and to secure this, the country, having paid heavily for deep trenches taken down into the bowels of the earth, will be pouring all the water of the country into them (two-thirds of it quite unnecessarily), and then paying to lift it out.

If adopted, such a system will last while the canals are as small as they are to-day and the waste lands are guarded from reclamation; while the drains are new and free of weeds; while drains and pumps designed for areas greatly in excess of the actual area are only serving the latter; while the cultivators have not learnt to take full advantage of the lowered levels; and while the evils of reduced red water are for a time mitigated by deeper drainage. This is just what happened fifteen years ago. No system, however, to which time is so decidedly hostile, can contain in itself the seeds of permanency. Weeds will come and come to stay, raising the water-level of the drains; areas under serious reclamation in the cultivated tracts will increase automatically as they do in Egypt; years of plentiful Nile supply will put the Government off its guard, and rice will assert itself; and the pumps and drains will gradually prove less and less able to keep down the water; and all this time the reduction of the red water of the flood will be telling steadily on soil and quality of crops.

Summing up and adding some further pertinent observations, we may say that pumping by zones possesses the following advantages over the system of single pumps at the tails of the main drains :—

(i.) It will be possible to maintain the ground water, and, with it, the salts, at a depth below the surface of the ground suited to each locality independently of the others. The maximum depth necessary will be secured at the minimum of cost.

(ii.) It will be possible to give a steep slope to the drains leading to

the pumps, which will increase the velocity of the water and help to keep down the weeds.

In the early years of the drains, when the channels are new, the weeds are not serious ; but as years pass on they increase in vigour and persistency, and eventually are a most serious factor in the economy of the drains. The sweeter the land the quicker the development of the weeds; but even in salted lands the surface soil of the drains becomes less salted, and eventually the weeds give nearly as much trouble as they do in the best lands.

Now weeds are greatly minimised by the presence of red water, and if such water is freely tailed into the main drains used as escapes, it will aid more than anything else in keeping down the weeds. With single pumps at the tails of the main drains such free use of red water will swamp the pumps.

(iii.) Pumping by zones will render the smaller secondary and tertiary drains independent of fluctuations in the water surface of the main and larger secondary drains, owing to heavy rain floods, irrigation, and washing.

(iv.) In rotation periods the pumps will keep the smaller drains dry if necessary.

(v.) Drainage water will be everywhere at least 1 metre below the surface of the fields far away from the drains. The tertiary drains will have a slope of $\frac{1}{3000}$ to $\frac{1}{5000}$, the secondary drains of $\frac{1}{5000}$ to $\frac{1}{10,000}$, and the main escape drains of $\frac{1}{10,000}$ to $\frac{1}{20,000}$, according to the depth of water. Generally the drainage water will be 2 metres below the level of the ground, and from 2·5 to 3·0 metres at the pumps. A main drain, even if it has its water surface $1\frac{1}{2}$ metres below the ground, and into which the minor drains flow by gravitation, will by no means ensure anything like such slopes or such depths.

(vi.) With the main drains flowing directly into the sea, they will be able to be used freely as escapes for the canals ; and in this way red water in flood will be assured to every acre of land in the Delta.

(vii.) With an assured low level for the drainage water and abundance of red water in flood, the productiveness of the drained lands will be increased to 100 per cent. over what it will be without such advantages. The land taxes on areas so reclaimed will be double what they would otherwise be.

(viii.) This extra depth of ground water and salts will greatly diminish the quantity of water needed for irrigation in summer, and the supply economised in the lands already under cultivation will go forward to irrigate the lands to be reclaimed.

(ix.) The cost of bringing irrigation water to the lands situated in the northern part of the Delta will be even greater than that of draining them, and as the system of deep drainage by zones will greatly reduce the

quantity of water required in summer, it will equally reduce the cost of providing reservoir water for summer irrigation.

In the flood also there will be further economies in the provision of irrigation; for when the drains, used as escapes carrying the red water escaping from the canals, rise above the surface of the ground in the midst of the salted lands of the *Berea*, the water they carry will be available for use for irrigation throughout the flood and early winter. Such water, as analysed to-day in flood in drains used freely as escapes, is well suited for irrigation and is so used. It will supplement that brought down by the canals in flood and allow of serious economies in the provision of irrigation water to localities where its provision in sufficient quantities will be otherwise very expensive. With drains pumped at their tails all this will be out of the question.

(x.) Drainage by zones of reduced area possesses this advantage, that we can introduce the system adopted by M. Victor Mosséri in Lower Egypt and recommended for adoption in France by the authorities appointed to examine the question of the reclamation of the swamped lands bordering the Mediterranean. This system consists in the pumping of the true infiltration water only, and allowing all other irrigation water to flow freely into the public drain wherever the water surface in the latter is just below the surface of the ground. There is an economy of 66 per cent. See paragraph 100.

(xi.) Pumping by zones will allow of the canals systematically discharging flood water freely and as freely sending it down the escape-drains. This will materially relieve the branches of the Nile in a high flood and be of great value. Tail pumps pumping all the escape water of the canals are absolutely opposed to the free use of flood water, and they are therefore not only no asset in flood but a minus quantity.

(xii.) Summing up, we may say that the system of drainage by zones ensures rich red water everywhere in flood and drainage of just such a depth as is suited to each locality. Only such drainage water as needs to be pumped is pumped: everything else reaches the lakes by gravitation, and this represents from two-thirds to five-sixths of the whole. Drainage by tail pumps, where you have to lift everything whether it needs lifting or not, will in the end be performed with an extravagance which will even be felt by the Egyptian Treasury if it is done thoroughly; and with results ruinous to the agriculture of the country if it is done sparingly.

If we compare the initial cost of drains, of which one set have their water surface 1·50 metres below ground-level and the other ·20 metre, we arrive at the following results which are epitomised from the table below:—

With 3-metre wide drains the latter is 200 per cent. more economical than the former.

With 5-metre wide drains the latter is 100 per cent. more economical than the former.

With 10-metre wide drains the latter is 94 per cent. more economical than the former.

With 20-metre wide drains the latter is 68 per cent. more economical than the former.

The cost of drains under the zone and tail pump systems may be thus compared:—

Cross Section of Drain. Slopes 1/1.		Water Surface 1·5 metres below Ground. Quantity and Cost per kilometre			Water Surface ·20 metre below Ground. Quantity and Cost per kilometre.		
Bed in metres.	Depth of Water in metres.	Cubic metres.	Rate. £	Cost. £	Cubic metres.	Rate. £	Cost. £
3·0	1·5	18,000	·02	360	8,000	·015	120
5·0	2·5	36,000	·03	1080	21,000	·025	520
10·0	3·5	75,000	·04	3000	51,000	·030	1530
20·0	4·5	156,000	·05	7800	116,000	·040	4640

If, further, we compare the cost of pumping the whole of the water 1·5 metres at one installation with the cost of pumping from $\frac{1}{3}$rd to $\frac{1}{6}$th of the water 3·0 metres at many installations, the latter will be found at least twice as economical and certainly twice as effective.

The weed clearance of drains whose water surface must not rise more than 1·50 metres below the ground would have to be so drastic and so often repeated per annum that it would cost very many times the clearance of drains which are only required to run. Especially would this be the case owing to the fact that plentiful supplies of red water kill weeds, and under the zone system we encourage the entry of such water, while under the tail systems, where everything has to be pumped, we discourage it.

84. **The lakes** cover an approximate area of 660,000 acres, thus subdivided: Menzala, 410,000; Borollos, 140,000; Edku, 45,000; and Mareotis, 65,000. Between high- and low-water level the areas vary considerably. All are shallow except Mareotis, which is deep. As we are only concerned with the question of drainage, we shall leave all other features alone. The mean annual evaporation of brackish water in the lake region is 1·27 metres, and consequently the water evaporated from the lakes annually is 3½ milliards of cubic metres, or one milliard more than the raised Aswan Reservoir. This Mussa Pasha Ghaleb has considered a valuable asset of the country and worth husbanding; it certainly is at Mareotis. This lake

evaporates annually some 340,000,000 cubic metres,* and as the Mex pumps to-day raise annually 520,000,000 cubic metres, it economises 40 per cent. of the total volume raised by evaporation and pumping. This evaporation saves the State some £11,500 per annum.

Edku, Borollos, and Menzala have openings into the sea, some of which are periodically closed by sand drifts. The water of Mareotis is pumped at Mex into the sea, and maintained between $-2\cdot70$ metres and $-2\cdot15$ metres (Richard). Lying, as it does, well below sea-level, the drainage into it is easy; and good slopes can generally be maintained for the higher lands. The mean cost of pumping this water during the last four years of which the records have been published has been £17,700. Without evaporation it would have been £29,200 per annum.

For the drainage of the areas occupied by Lakes Menzala and Borollos we think that the proper solution is to wait till the lands above sea-level have been reclaimed by basin or perennial irrigation. When that has been done and, owing to the construction of the Wadi Rayan and other measures, there is no longer any fear of a breach of the Nile banks, if enough water is then available for irrigation, it will be wise to take the main drains across the lakes in embankment and let them flow directly into the sea, pumping the low lands of the lakes into the main drains. Nowhere will the superiority of drainage by zones be more evident than here. With a single pump we should have to lift the whole drainage of Lower Egypt an extra metre or metre and a half, in order to add the lake areas to those of the drained lands. Even a rich country like Egypt would begin to be at its wits' end to find these ever-increasing sums.

In Italy they take their main drains across the low lands of the delta of the Po, at a height of from 1 to 1½ metres above the level of the land. The main drains flow into the Adriatic, and the secondary drains are pumped into them.

The region draining into Lake Mareotis stands on a different footing from every other part of Lower Egypt, owing to the great depth of the lake. Western Behera has steep slopes, and as the drains have to be pumped whether you lift the water 1 metre or 10, it is not a question of comparative efficiency: it is only a question of the Egyptian Treasury supplying the funds. The best solution for this part of Behera is to keep on pumping the drainage water of the lands above the level of the lake, at the level at which it is pumped to-day. In 1895 the amount of water pumped was 175 million cubic metres; in 1900 it was 316 millions; in 1905 it was 411; and in 1910 it was 487 millions. When the million acres of land above sea-level needing reclamation have been reclaimed, it will be time to think of draining lands 4 metres below sea-level. It is unsound financially to lift the drainage and escape water of 410,000 acres 5 or 6 metres instead of 3 for the sake

* Taking the area of evaporation as given in the Irrigation Report of 1898.

of draining a lake whose area is only 65,000 acres. Especially is this so in Behera, where the lake lies at the tails of canals notoriously inadequate for the existing irrigation on them. In Eastern Gharbia where they reclaim land quickly by small pumping installations for drainage, they can put from a third to half their area every year under rice; while in similar lands in Behera they reclaim salted clay slowly indeed, and are allowed to put in one-fifth the area every third year under rice, and that by special permission. The irrigation canals of Behera will have to be increased greatly and then fed by either the doubling of the Rayah Behera through the sand dunes, so skilfully managed by Mr Foster, or by a barrage on the Rosetta branch which will cost before it is completed £1,000,000. The former is unhesitatingly the sounder project of the two.

The Rosetta branch to-day is the drain of the whole western half of the Delta and collects its seepage water at the Mehallet-el-Amîr temporary dam at a low level, for utilisation in summer. If a barrage is made, the water will be held up to a high level, as at Zifta on the Damietta branch, which will diminish the value of the reservoir and create a centre of land deterioration round itself. But what is far more serious is the fact that the Rosetta branch is the heir to the Nile. The Damietta branch is silting up and becoming yearly more dangerous in flood; while the Rosetta branch is scouring, and will, in some near very high flood, have to carry not only its own supply but some of that kept out of the Damietta branch at the Delta Barrage. Barrages built on such a channel are to be deprecated if we look some years ahead.

In draining Mareotis we lose the asset of evaporation already noted, which means some £11,500 per annum to the country, and pays for the annual earthen dam in the Rosetta branch, with money to spare.

85. **The sand dunes** north of the lakes have their valleys cultivated with dates, melons, and fruit trees. Reclaiming sandy land is very easy, as they have found at Abukir. If therefore water could be provided in liberal quantities at Beltim, the wide level plain of sand to the east of the town, thousands of acres in extent, could be easily reclaimed, and become a really valuable and self-supporting fellahin colony.

86. **Upper Egypt** remains to be considered. In the Fayum, with its steep slopes and deep trenches scoured through the ground, drainage is easy and effective. In the Nile Valley we have the deep trench of the Nile on one side and of the Yusufi on the other, with their waters at a low level for eight months in the year, lowering the ground water everywhere. The land, when not ruined by faulty irrigation, is free from salt. Drainage should be no more needed here than in the lands clustered round the apex of the Delta in Lower Egypt. What are really needed are escapes for the irrigation canals, to prevent water-logging and secure red water everywhere in flood. Such escapes exist to-day, though they are called drains. They

afford a passage to the excess water of the canals—water which is free from salt and turned either into the Nile or into the Yusufi, and used lower down for irrigation and drinking purposes. During flood, when both the Nile and the Yusufi are at a high level, and incapable of receiving the waters of the escapes by gravitation, these escapes should be pumped into the Nile and Yusufi. For this purpose there is one pumping installation north of Minia, though there ought to be four or five. The existing pumping station was erected in 1902 and 1903 and is a good object-lesson for us. In anticipation of difficulties, though pumping had only to be resorted to for a few weeks per annum, the irrigation authorities closed all the tails of the canals terminating at the main escape-drains with strong earthen dams, and would have deprived the country of red water, had not the landowners had openings for their water-courses into the escape-drains. The cultivators used them as escapes for the canals, letting the waters from the tails of the canals run through them into the mains. The inexpediency of this is apparent to-day, and the canals are being provided with tail regulators. Here, there is no effort made to keep the water-level in the escape-drains at any fixed level, but to get it to move on ; and there is practically no drainage water at all.

In the old perennial area, dating from 1874, there is one bad stretch of salted land between Magaga and Feshn, with Fant as a centre. It owes its ruin to the high level of the Ibrahimia Canal as it traverses a sandy tract. All sorts and conditions of men have been trying these forty years to reclaim these lands by shallow drains, and yet they always remain the same. If the area were divided into zones and provided with 2-metre deep drains and pumping stations where necessary lifting water into the mains, the whole tract would be reclaimed. Nothing else will ever reclaim it except the wholesale lowering of the Ibrahimia Canal. The Ibrahimia Canal has always been maintained at a high level. It was so in the old tracts : it is the same in the newly converted tracts. Between 1902 and 1909, some 400,000 acres of basin land on the left bank of the Nile were added to the perennial area, and are known to-day as the converted basins. If 10,000 acres had 20 acres of high land anywhere, all the canals, big and small, were held up above the level of the country, to give the latter free flow irrigation. In Lower Egypt, in the early years of the Occupation, we looked on lift irrigation as a blessing and gave it to hundreds of thousands of acres. These high-level canals might be lowered in very many places with advantage to the country. They have permanently injured extensive tracts which will, at some future day, need heavy drainage, while east of Lahun they have begun another Fant. If this tract is not immediately divided into zones provided with 2-metre deep drains and pumping stations, it will become absolutely sterile. It may have to be reconverted to basin irrigation.

In these converted basins, the vicious system inaugurated in 1902 in the old perennial area, of canals closed at the tails by earthen dams, had to be carried out by the Director-General of Conversion Works. Between the canals, major and minor, so ill-treated, there have been dug shallow drains with their theoretical water surface 50 centimetres below the ground. They have been excavated in thousands of kilometres. They serve one purpose. They cannot drain anything through their weedy, choked-up, little bodies, but at their tails they open into the main escape-drains, and thus perform the vicarious work of escapes for the canals. As the canals are all closed at their tails, the tail waters of the canals are run into the tails of these drains and so reach the main. If the drains were real drains, as they are in Lower Egypt, they could not perform this vicarious work without disorganising the drainage. The irrigation officers on the spot are rectifying all this (indeed the Director-General began it in the last basin converted) by putting regulators at the tails of the canals and letting the escape water enter as *bona-fide* escape water. You cannot have red water for your fields if you decant it in the canals. Once all the canals can escape easily themselves, all these drains, except those true drains which ensure a free passage for the water finding its way into the natural deep depressions of the old basins, might with advantage be abandoned. The land occupied by them would bring back to the State some £150,000 in cash and some £3500 per annum in land tax. The money might profitably be spent in providing four or five good pumping stations for the escape-drains into the Nile and the Yusufi in flood."

87. **The economy of escape-drains** covers the questions how the escape waters of the canals and watercourses should enter the escape-drains, how the drainage water should enter, the depth at which the ground water should be kept, the duty of drains, and the important question of weeds and clearance. We shall take each separately.

The *escape waters* of the canals and larger watercourses should be allowed to enter the escape-drain by means of regulators at the tails of the canals, and by pipes of a certain size at a high level for the tails of the watercourses. The former should be used in winter, when there is a sudden check in irrigation owing to rain or threatened rain, and when the canals have to be dried in the closure week. In summer they should be used to dry the canals in closure week, while in flood they should be used to allow of the free flow of red water to prevent the red sediment being deposited in the canals and not on the fields. The pipes for the watercourses should be about 10 centimetres in diameter.

The drainage water, if by free flow, should be allowed to enter through pipes of sizes proportional to the area to be drained, and for this purpose Mr Dupuis has drawn up a table, which is given below. It assumes everywhere a clear head of 25 centimetres on the pipe. When that can be

obtained the discharge is sufficient, provided no rotations are employed. Rotations on drains open a road for an appalling amount of bakshish and worry to the cultivators. They, moreover, cause water to stagnate on the lands and throw back land reclamation. They are a very makeshift means of keeping the drains low.

On this subject Sir Hanbury Brown wrote in 1902:—

"In a note from one of the irrigation officers I was somewhat staggered to find that he seemed to take credit to himself for having introduced rotations on drains as a good system to apply to drains. Such a creed can only be condemned as rank heresy. The flow of a drain should never be stopped. If the drains of liberal section are abused, the remedy should be to shut off the outlets of canals where the water starts on its way to the drains."

We now give a departmental table for the sizes of irrigation and drainage pipes.

TABLE 208.—DIAMETERS OF IRRIGATION AND DRAINAGE PIPES, CULVERTS, AND SYPHONS (Dupuis).

Area served.		Drainage Pipes.	Irrigation Pipes.	Culverts and Syphons.	Remarks.
From (acres)	To (acres)	Diameter in metres.	Diameter in metres.	Diameter in metres.	
1	25	0·10	0·10	0·20	For pumps for land reclamation 30 cubic metres of water per acre per 24 hours should be allowed.
26	50	0·15	0·15	0·20	
51	100	0·20	0·20	0·25	
101	200	0·25	0·25	0·30	
201	300	0·25	0·30	0·35	
301	400	0·30	0·35	0·40	
401	500	0·30	0·40	0·45	
501	600	0·35	0·45	0·50	
601	800	0·40	0·50	0·60	
801	1000	0·40	0·55	0·65	
1001	1200	0·45	0·60	0·70	
1201	1400	0·50	0·65	0·75	
1401	1600	0·50	0·70	0·80	
1601	1800	0·55	0·75	0·85	
1801	2000	0·55	0·80	0·90	
2001	2200	0·60	0·85	0·95	
2201	2400	0·60	0·90	1·00	
2401	2600	0·65	0·95	1·05	
2601	2800	0·65	1·00	1·05	
2801	3000	0·70	1·05	1·10	
3001	3200	0·70	1·10	1·15	
3201	3400	0·75	1·15	1·20	
3401	3600	0·75	1·15	1·25	
3601	3800	0·80	1·20	1·30	
3801	4000	0·80	1·20	1·35	

If the drainage water of the fields is pumped, the entry into the public drains should be by an opening of twice the diameter, for the size of the pump is fixed by the Department, and it is there that the control should be exercised. This larger opening should be placed high, so as to prevent abuse.

The depth at which the ground water should be kept to give the best results has been studied very carefully of recent years in Egypt, and the question has been dealt with very fully in CHAPTER I. When ground water is over 2 metres below the surface of the field the best results have been obtained for cotton in all lands except those bordering the lakes or the Mediterranean. When, however, we come to the belt near the sea, the best depth is from 1¼ to 1½ metres below ground-level, for reasons already given in paragraph 82. To secure depths of 2 metres everywhere in drained land which slopes towards the drain, a depth of 2½ to 3 metres is needed at the pump near the main drain. It will be shown in paragraph 91 how depths of over 3 metres may be needed at the pump in flat level land to obtain even 1 metre everywhere in the fields. Such depths can only be obtained by pumping installations established along the drains under the system of drainage by zones.

The duty of escape-drains may be taken as between 10 and 20 cubic metres per acre per day, according as we are in land where little rice culture is needed or where rice has frequently to be resorted to, to refresh and renew the land. Very few serious experiments have been made to find out the real duty of drains. It will be seen in paragraph 92 that Mr Hood considers 30 cubic metres per acre per day as the duty of drains draining estates of 3000 acres. For the duty of the main drains we have a few observations which we can utilise.

The rise and fall of Lake Mareotis, given in paragraph 84, gives us a means of measuring approximately the discharge at the tails of drains which serve an area of some 300,000 acres of cultivated land. According to Mr Verschoyle's figures in the report for 1898, the lake has a mean area of 65,000 acres, or 273,000,000 square metres. The mean annual rainfall is ·23 metre per annum, and represents 63,000,000 cubic metres. The evaporation annually is 1·27 metres, and represents 347,000,000 cubic metres. The quantity pumped per annum during the last four years of which we have records has been 520,000,000 cubic metres. The water which enters the lake plus the rainfall equals the evaporation plus the pumping. Mr Verschoyle, who knew the region very well, considered the water which really entered the lake owing to rainfall as twice the actual rainfall over the lake, or twice 63,000,000, but the actual figure is comparatively small, even when doubled. We have therefore a simple equation:

$$x + 2(63{,}000{,}000) = 347{,}000{,}000 + 520{,}000{,}000$$
$$x = 741{,}000{,}000 \text{ per annum.}$$

The amount which enters daily is therefore 2,300,000 cubic metres. As this comes from 300,000 acres, it represents 8 cubic metres per acre per day. It has already been shown that the canals of Western Behera which drain in this direction have a very indifferent supply, and landowners are allowed to put in rice only on one-fifth this area every third year, while in other parts of Lower Egypt they often put in one-third every year.

The Wadi Tumilat pumps lift per annum 63,000,000 cubic metres off about 13,000 acres of cultivated land, of which some 5000 need no drainage at all. This represents 13 cubic metres per acre per day for the whole area, or 21 cubic metres per day for the drained area.

In the second edition of this work was given a table showing how much water was discharged by certain of the Gharbia drains in 1898 measured by Ismail Bey Sirry and Mr Tottenham. Off an area of 467,000 acres of reclaimed land lying near 353,000 acres of waste land and land under reclamation, the drains were discharging 104 cubic metres per second in flood time, of escape and drainage water. Of this area of waste land, and land under reclamation, as it was in 1896–97 during the Land Tax adjustment operations, but a small fraction was under reclamation. If we say one-tenth was under reclamation, it is by no means a low proportion. We may therefore say that the area off which the drainage water came was 467,000 + 35,000, or 500,000 acres in all. The drains were discharging 104 cubic metres per second, or 9,000,000 cubic metres per day. Each acre was therefore discharging in flood 18 cubic metres per twenty-four hours, or one cubic metre per second was discharged by 5000 acres.

In 1911 discharges were taken by Mr G. B. Ireland, Director-General of Projects, on certain of the drains in Gharbia. The total area drained was 453,000 acres; of this 261,000 were under cultivation and 192,000 were waste. Of the 261,000 acres under cultivation, 172,000 acres were under crop in summer, and of this latter area 27,000, or 15 per cent., were under rice. The mean discharge of the drains was 41 cubic metres per second in flood, and 34 cubic metres per second in winter. The summer discharge, from an independent series of observations, was taken as 4 cubic metres per acre per day.

Now, 41 cubic metres per second equals 3,500,000 cubic metres per day. This means in flood, for the 261,000 acres, a discharge of 13·4 cubic metres per acre per day. A discharge of 34 cubic metres per second equals 3,000,000 per day. This means in winter, for the 261,000 acres, a discharge of 11·5 cubic metres per acre per day.

The drains discharge all that the canals bring to them. Of the water discharged, about half may be taken as *bona-fide* drain water and half as escape water from the canals.

Weeds are a very important factor in the economy of the drains. All

the Government reports bear witness to the seriousness of this question. Reference should be made to paragraph 89.

French engineers who have studied this matter distinguish two classes of such weeds—those which simply carpet the bed, and those (grasses) which rise from the bed to the surface. The former are of small importance, and may be allowed for by diminishing the section of the bed by 10 centimetres all over. The latter are of great importance, both because they diminish the area and because they lead to an increase of the wetted perimeter which it is impossible to estimate. In rapid streams these weeds are laid flat and their effect is less important, but it increases in importance in proportion as the current becomes sluggish and the weeds rise towards the surface.

Reference to observations on this point will be found in *Alimentation du canal de la Marne*, etc., by M. A. Picard.

Weeds grow in clear water far more readily than in muddy water, especially deep muddy water. Consequently, where the main drains and important secondary drains are real escapes for the muddy waters of the canals and not sham ones, such waters are an enemy of the weeds. Canals have, on occasions, weeds in them, but they never attain the proportions they do in the drains which carry only clear water. This is no small reason in favour of keeping all the drains as free carriers of escape water. So far the large drains. When we come to the tertiary and smaller drains which contain no escape water, the only chance for them to be effective is to give them a good slope and keep them deep and narrow. Even if the water in the main drain is maintained at a depth of $1\frac{1}{2}$ metres and more under ground-level, such slopes may be obtained by gravitation in certain localities, but generally it will be found far more effective to pump them. Such pumps can absolutely dry the drains in rotation periods in summer and so help in the keeping down of weeds in the small drains.

The Government has been employing certain types of weed cutter, but the question of preventing weeds is far more urgent than that of periodically removing them. Weeds must be cleared two or three times per annum, and the majority of drains, in spite of weed clearance, are no carriers of drainage water for many months per annum. Many drains only act satisfactorily during the periods of closure of canals when no drainage water is entering them or when rice is greatly restricted and canal water very scarce.

Weeds are greatly encouraged in canals and drains by the wooden supports of aqueduct pipes and temporary bridges. It is for this reason that all cross pipes should be syphoned if possible, and all aqueducts and bridges be of one span from abutment to abutment.

88. **The Existing Drains of Upper and Lower Egypt.**—The lengths of the drains of Lower Egypt have been given in paragraph 75 of

CHAPTER VII. In 1910 there were in Lower Egypt:—1030 kilometres of drains with a bed width of 8 metres and over, 630 kilometres with bed widths between 4 and 8 metres; and 1730 kilometres with under 4-metre bed widths; or 3390 kilometres in all. The length of the existing drains in Upper Egypt was 3030 kilometres, most of them very small and of little value as drains.

Of the drains of Lower Egypt the second edition of this work noted as follows:—

"It has been the habit hitherto to construct the drains of comparatively small capacity at first, to throw the spoil well back, and gradually increase the channel as cultivation extended and the quantity of water needing removal became more considerable. An attempt has also been made to keep the drains of such a section that the drainage water will be in soil, but the amount of water which can be discharged from rice fields and land under reclamation is so enormous that there will never be any limit to the size of the drains. The time has surely come for the Department to construct its drains of suitable section, to meet a fixed discharge whether in soil or out of it, and to provide the drains with solid, substantial banks, leaving the proprietors to drain by gravitation if they can, and if they cannot to drain with pumps. A man who has flush irrigation for his fields as a rule, should consider himself fortunate if he can drain off *all* his surplus water, be it by pumping or by gravitation. As the water which should be drained off the field in order to ensure a good and healthy crop should be one-third the water needed for irrigation, it will readily be seen that it is far more convenient for cultivators in the dense clay soils which constitute the valleys of all the deltaic formation to have flush irrigation and lift drainage, rather than lift irrigation and flush drainage. For it must be remembered that in the tracts to the north of the line so often spoken of, where the deltaic formation is well developed and the country provided with both longitudinal and transverse slopes, the sandy clay soil is confined to small strips bordering the canals, and lying at a level well above the dense clay soil which monopolises the whole of the valley, and especially the lowest parts where the drains should be. In all these tracts the canals can be run at such a level that the sandy clay strips will receive lift irrigation, and the whole of the rest of the valley flush irrigation throughout the year, by direct flow in flood and with the aid of regulators and rotation in winter and summer. Flush irrigation and lift drainage under these conditions can do no harm to these clay tracts, provided the canals all run freely and fully in flood when they are charged with the rich muddy waters of the Nile, and the drains are well designed down the bottoms of the depressions. Drains which to-day are capable of but indifferently draining very limited areas, where favourably situated landed proprietors on the banks can discharge any quantity of water they like into them, will be capable of thoroughly draining far larger areas when the water discharged into them is by lift and consequently restricted to the actual requirements of the lands.

In the above paragraph I have recommended flush irrigation by rotation in winter and summer only and by free flow in flood. In the first edition of this work I recommended irrigation rotations in flood, but after an examination of these lands through the floods of 1895 and 1896 in localities where the flood supplies were much restricted, I have learnt to deprecate such action. The lands need

every drop of red muddy water which they can get, and the proper procedure is to increase the canals when necessary, and let them run freely every day of the red-water supply. While making these inspections I was daily reminded of the truth of Colonel Ross's remark already quoted, that the greatest calamity which can overtake any part of Lower or Upper Egypt is a red-water famine. Such a famine exists to-day in many places.

When the drains traverse high lands, as they do at every minor canal crossing, the banks of the drainage cuts should be provided with iron pipes to limit to their minimum requirements the water which will be discharged freely into the drains. Some excellent examples of this procedure are to be seen on some of the First Circle drains constructed by Sir W. Garstin.

Previous to the great distribution and sale of waste lands in Egypt in 1884, the high lands near the canals in the north were alone cultivated, and then drainage water was poured freely over the lower-lying wastes. The handing over of these wastes to influential bodies and persons without in any way conserving drainage rights for the existing cultivation has caused the ruin of many smaller proprietors and the deterioration of much good land. These lands have a first claim on the Government.

Some agriculturists state that *washings* of the land in winter are more effective than in summer: some say, because the water is clear in the winter, and capable of dissolving the salts; others say, because the water is cold in winter. Anyway, even where crops are grown, drains can do much good by permitting of the systematic washing of the clover fields in winter. Indeed, some good agriculturists prefer keeping their lands free from salt on this method, to resorting to the more costly and difficult cultivation of summer rice. This last statement of course applies to lands which are capable of producing good clover.

All drainage channels which flow into the lakes should be well dredged into the lakes so as to induce a good flow, and each of the main drains of any magnitude should be provided with a grab dredger to keep them clear of weeds and rushes.

It is of no use tailing a drainage cut into the sea through the sand dunes. The storms which accompany the north-west winds, when they blow strong, obliterate the drains. All drains should either be tailed into the lakes or into the openings kept clear by the main branches of the Nile in flood.

Drains carrying clear water, as they generally do, are very liable to become full of weeds and rushes. Grab dredgers have already been recommended for the main drains. Where possible, the construction of temporary dams for a limited time in summer and the entry of salt water into the drains are very destructive of fresh-water plants. For the smaller drains the best procedure is to put in temporary dams, dry the different reaches of the drains one by one, and weed clear the beds and sides.

On all drains, wooden or iron bridges of a single span supported on masonry abutments raised well above damp and saturation level should be most liberally provided for all road crossings. If bridges are not constructed at all the crossings, the villagers throw in cotton stalks to obtain a firm footing for their cattle, and often hold up as much as a foot of water at each place."

The great feature of all the Government minor drains, wherever there is not much red water in flood, is an extraordinary growth of weeds. Many

drains are so full of weeds that it is impossible to tell which way the water is flowing.

89. Extracts from Government Reports.

Mr Verschoyle's Report, 1896.—"While these levels were being taken a reconnaissance was made of the desert lying between the Natron Lake Valley and Lake Mareotis. The reconnaissance was carried far enough to show the impracticability of the proposal to dispose of the Behera Province drainage by connecting Lake Mareotis with the Wadi Natron.

The length of the drain would have to be almost 80 kilometres for the greater part of the way in 20 metres depth of cutting through desert and ridges of drifting sand. If it were an easy matter to make the connection, it would not be an easy matter to maintain it. It was not expected that anything would come of this proposal, but it was thought worth while to investigate the ground sufficiently to settle the question, which has been done."

Mr Verschoyle's Report, 1898.—"With improved drainage throughout Behera Province, the amount of water turned into Lake Mareotis has been largely increased.

A rainfall of 1 inch in the vicinity of the lake means an increase in volume of the latter equal to 7,000,000 cubic metres; in 1898 12·32 inches fell.

Before leaving the question of drainage, one word must be said upon a subject which is yearly assuming greater importance. I mean the yearly maintenance of the drains.

A very considerable mileage of channel has been added, and before the system is completed this mileage will be still further increased.

The annual clearance and maintenance of these channels will necessitate a very heavy charge upon the yearly repairs budget. Already the pressure is felt, and it is certain that in a few years' time the difficulty of providing the necessary funds will be much aggravated."

Sir William Garstin's Report, 1900.—"Between 1885 and 1900 (inclusive) a total sum of £1,285,412 has been expended on drainage works in Upper and Lower Egypt. For the above, 3145 kilometres of new drains have been constructed and 555 kilometres of old badly aligned drains enlarged and remodelled."

Sir William Garstin's Report, 1902.—"With reference to Behera, Sir H. Brown quotes statistics given by Mr Williams, the Inspector of Irrigation, to show how, thanks to improved drainage, the areas of cotton and winter crops have increased since 1894. In that year the area under cotton was 149,826 acres; in 1902, 240,080 acres. The area under winter crops in 1894 was 268,050 acres, while in 1902 it was 374,894 acres. Thus the cropped area of Behera Province has increased by nearly 40 per cent. in the last eight years. In the other provinces reclamation works have likewise increased the cultivated area, though not to the same extent, the reason being that in Behera larger areas of reclaimable swamps existed than in other parts of the country.

Before leaving the subject of drainage, I would draw attention to Sir H. Brown's remarks regarding the quantity of water carried off by drainage channels. With these remarks I am entirely in accord. The only possible way in which to reduce the over-flooding of the drainage lines is by controlling and restricting the supply of water in the irrigation channels.

For the drainage of low-lying lands bordering the lake, he recommends the introduction of the system long in use in Italy and Holland, *i.e.* of running the drains at a high level through these tracts and pumping the water into them. This system was long ago advocated by Sir William Willcocks. It is no doubt the most satisfactory way of draining these water-logged areas, and at the same time arranging for the successful drainage of the higher lands. It is, however, rather difficult to introduce into Egypt, where there is so little combination among land-owners and where so many of the properties are very small. Nevertheless the system is worth a trial."

Sir H. Brown's Report, 1902.—"The system of embanked public drains flowing by gravitation into the sea, into which landowners can pump their own drainage, is a more satisfactory system, certainly from the Public Treasury's point of view, than the existing arrangements for the Mareotis drainage.

There is a large area of land uncultivated and untaxed in the north of the Delta which is only a little below the level of the land it is possible to cultivate. If the owners of such land were to pump their drainage, the land would be readily cultivable provided there be a public drain within reach to pump into. All that is required is to surround the land with an exterior ditch to act as a catch drain, and to set up a pump or pumps at the most convenient points for pumping into the public drain.

It has been urged against such an arrangement that the expense of pumping the drainage water would be too great for the operations to be profitable. But if it pays to lift water for irrigation to raise crops on high lands which get free flow drainage, it must pay to have free flow irrigation and lift the drainage water, as the amount drained off the land must necessarily be less than that used for irrigation. How much less will depend upon the care with which the irrigation is conducted. But there is no reason why this system should not be applied on any scale to the low lands bordering the lakes. . . . The reason why no definite project for the reclamation of these lands has yet been elaborated by the Irrigation Service is that no maps exist of this inhospitable country, and we are still waiting for them.

With reference to the question of pumping the drainage water, I think Sir W. Willcocks' warning concerning large areas drained by single installations is worth quoting. The quotation is from his lecture of the 25th March 1903 on *Irrigation on the Tigris*: 'The important point is that numbers of small pumps should be placed on the banks of the main drains draining small areas and discharging direct into the mains. Such pumps might be actuated by one central electric station for reasons of economy. The results of such drainage would be immediately apparent. The early failures of large reclamation works were nearly always due to the extensive areas drained by single installations.'"

Report by Sir A. L. Webb, 1907.—"The maintenance of existing drains, however, has become a serious matter, and frequent and justifiable complaints have been received, especially after heavy rains in the northern tracts, that the drains would not carry off surplus water. The Commission appointed by the Khedivial Agricultural Society to inquire into the causes of the diminution of the cotton crop have also strongly represented the necessity for improved drainage. Whenever the Finance Department can find its way to increase the grants, money could not be better spent than on the maintenance of the drains."

Report by Sir A. L. Webb, 1908.—" . . . the trouble at present in the drains

of the Second and Third Circles is mainly due to the growth of weed, which is being constantly cleared by hand and steam weed cutters, the latter being most useful in all circles. . . .

From special grants a sum of £83,685 was spent, being £20,000 in excess of that of the previous year. In addition, a sum of £41,069 was spent in maintenance and clearances, being £17,000 in excess of the previous year. Notwithstanding this increased expenditure, it cannot be said that the drainage is satisfactory, although improvement has certainly been made in recent years. Complaints are frequently received that the drains are full of water and not working properly, especially after heavy rain. In most cases this is due to want of weed clearance or insufficient slope in the water surface."

Report by Mr C. E. Dupuis, 1909.—"The vigorous growth of water weeds in almost all drains causes a serious obstruction to their flow, and the satisfactory removal of these weeds presents a problem of extraordinary difficulty.

The carelessness of the owners of private drains permits of the washing down of large quantities of soil into the main channels, which causes them to silt and deteriorate rapidly, and it is almost impossible to arrange to clear them as frequently as is desirable.

It has been repeatedly urged that large areas of badly situated lands can be satisfactorily drained only by lifting their drainage water into the main drains, which in many cases cannot be always maintained at such a level as to give satisfactory results by gravitation alone.

The establishment of large pumping stations at the ends of the drains has been advocated, and they would no doubt do much good, especially in their immediate neighbourhood; but the cost of the general lowering of the beds of the drains to the extent that would be required to render this proceeding fully effective would be enormous, the difficulties of maintenance would be seriously aggravated, and it is doubtful if the effects of such pumping at large stations at the extreme ends of the drains could be made to be felt at the remoter parts of the system.

The installation of small local pumping stations for the drainage of properties or areas would, it is believed, be found to be more effective, and probably cheaper in the end, but the question is a very difficult one, and will require long and careful study and a long time for execution.

In the meantime it can only be urged again that the proprietors of ill-drained lands can in many cases improve their condition by constructing a system of private drains of sufficient depth, and keeping the water in those drains at a suitable level by pumping into the nearest Government drain.

The essential function of a Government drain is held to be to provide a means of removing the drainage water which is poured into it by private drains; but experience has shown that it is impossible to ensure that the water of the Government drains shall always be maintained at a sufficiently low level to guarantee effective drainage to all lands by gravitation alone, just as it is impossible to guarantee flow irrigation from the canals; and, as in the case of the canals when the water is too low to give irrigation to the land by gravitation, the water must be lifted from the Government canals into the private canals, so in the case of drains when the water is too high to give effective drainage by gravitation, the water must be lifted from the private drains into the Government drains.

Some day it may be possible to provide Government drains that will always give

efficient drainage to all lands by gravitation alone, just as it might be possible to give flow irrigation to all lands; but there are objections to both courses, the most important being the impossibility of ensuring a reasonable and moderate use of water by private individuals when such use is too greatly facilitated, and in any case even where such conditions are held to be an ideal consummation, they are very far from realisation."

Report by Mr C. E. Dupuis, 1910.—"There seems to be a rather general impression that by the institution of some system of pumping drainage on a large scale through Government agency, great improvements could be rapidly effected in the general condition of the drainage of those portions of the country where drainage is now defective.

This is scarcely correct, as the institution of large pumping stations by themselves would have little but a local effect until the whole system of drains leading to the pumps had been deepened and adjusted to the new conditions.

The existing drainage system, defective though it may be, has taken a great many years and the expenditure of a very large sum of money to construct, and it would probably require as much time and money again to remodel the whole system to suit the changes apparently contemplated.

The maintenance of the existing system of drains in a high state of efficiency is a sufficiently difficult and costly business, and this difficulty and cost would be permanently increased by a general lowering of the drain beds apart from the first cost of such lowering."

"TABLE 209.—PUMPING AT MEX (1895–1910).

Season (Year).	Rain-fall in milli-metres.	Maximum Level of Lake. R.L. metres (Richard).	Maximum Level of Lake. Date.	Minimum Level of Lake. R.L. metres (Richard).	Minimum Level of Lake. Date.	Quantity of Water pumped. Millions of cubic metres.	Cost in Thousands of £.
1895–96	265	−2·15	Mar. 17	−3·15	Aug. 22	175	7·6
1896–97	217	−2·03	Jan. 7	−2·92	Sept. 11	217	8·1
1897–98	356	−2·17	Jan. 23	−3·20	Aug. 27	227	8·7
1898–99	302	−1·95	Feb. 18	−3·26	Sept. 16	285	8·4
1899–1900	210	−2·29	Jan. 27	−3·29	Aug. 11	203	9·4
1900–01	263	−2·18	Jan. 19	−3·23	Aug. 17	316	14·2
1901–02	217	−2·31	Jan. 4	−2·85	Aug. 16	385	13·3
1902–03	286	−2·44	Jan. 23	−2·78	July 4	396	12·5
1903–04	108	−2·18	Dec. 24	−2·78	Mar. 19	310	10·2
1904–05	246	−2·21	...	−2·94	May 13	454	12·7
1905–06	160	−2·20	Dec. 29	−2·72	Mar. 27	411	14·7
1906–07	166	−2·20	Jan. 6	−2·83	Mar. 10	430	22·9
1907–08	243	−2·15	Jan. 21	−2·78	April 15	523	21·4
1908–09	279	−2·14	Dec. 13	−2·62	July 27	496	16·3
1909–10	178	−2·05	Dec. 12	−2·76	April 15	571	16·9
1910–11	224	−2·25	Jan. 15	−2·71	Mar. 1	487	16·2"

90. **Land Reclamation by Basin Irrigation.**—We quote from the second edition of this work:—

"Having finished with the principles on which the main drainage of the Delta should be undertaken and which interest the State, we now come to the details that concern individual proprietors, and which may be called land reclamation. I personally consider a wholesale return to basin irrigation as the true solution of the problem of reclaiming the waste lands of the Delta, but for many years to come the State will continue its present policy of wasting the flood waters of the Nile and doing what it can with the summer supplies alone; and consequently reclamation by wholesale basin irrigation will be outside the field of practical politics. The Government will not undertake it, and it will be beyond the capacity of private individuals and syndicates.

Mohamed Ali attempted the reclamation of some of the lands by an ingenious

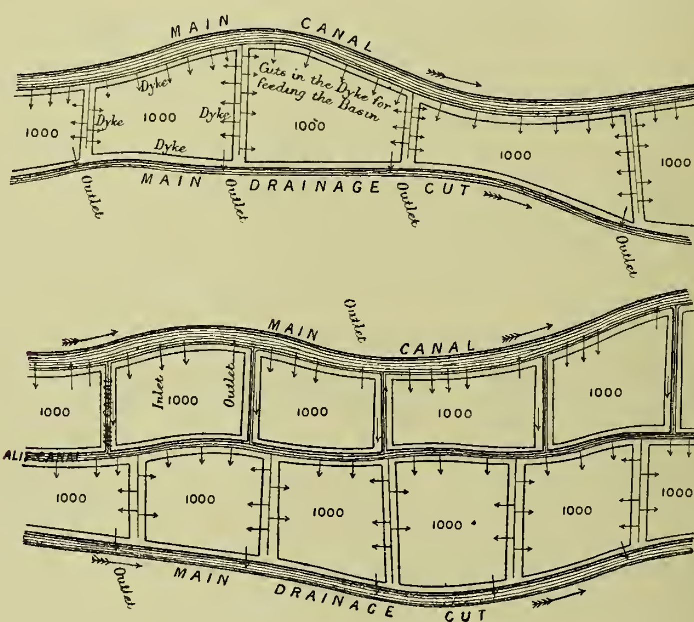


Fig. 34.

method of warping or modified basin irrigation. The one idea in his time was the cultivation of cotton, and the reclamation of these lands was subordinated to that idea. If the land had been thoroughly reclaimed and then put under cotton by rotation for one year and warped the next, the best results might have been anticipated, for the system of warping which he adopted was most ingenious. The lands were divided into basins of about 1000 acres each; they were provided with canals for filling, banks for retaining water, and drains for discharging it. The following systems were adopted :—

1. When the drainage cut was near enough to the canal to allow of one system of basins, the land was divided into a series of basins of 1000 acres each, reaching up to the drainage cut. The basins were fed direct from the canal and drained into the cut as shown in fig. 34. These basins were filled yearly, or every second or third year, according to the capacity of the drainage cut. The ordinary method adopted was to let the water run continuously over the fields,

and be discharged without interruption. This succeeded very well with water taken from the Nile, or from canals with a velocity similar to that of the Nile. Canals with a checked velocity, which had lost all the coarser particles of matter held in suspension, had to be differently treated. The water from these had to be retained for fifteen days on the land and then discharged. This process had to be continued throughout the flood. By this means a deposit was obtained of all the particles held in suspension.

2. When the drainage cut was too far off to allow of only one system of basins, the following plan was adopted. The basins near the canal were fed from the canal and drained back into the canal. This presupposed a canal with a very considerable discharge. The basins which were further off were fed by 'Alif' (Arabic for thousand) canals and drained direct into the cut. The basins near the canal were flooded every year, had high banks, and contained superior land. Rice, followed by clover or barley, was the crop sown.

If this system had been long continued, the lands would have been thoroughly reclaimed and rendered capable of producing wheat, beans, and Indian corn. But long before the land was sufficiently reclaimed to warrant cotton cultivation, the warping was abandoned and cotton cultivation begun, and in a few years the lands returned to their barren condition over nine-tenths of their area, while sickly fields

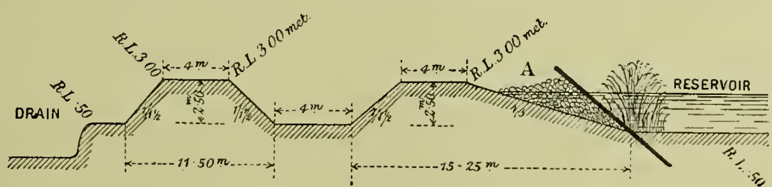


Fig. 35.

of cotton continued to be cultivated in patches. In 1887 I proposed the reconstruction of some of these basins, and received £1500 from the Daira Sania, to whom the land then belonged, for that purpose. With this money I was able to begin the reclamation of 5000 acres of this land, and in three years had brought considerable areas under barley and clover, when the neighbouring villagers asked the Daira to allow them to sow cotton and offered them a tempting rent. The Daira resigned the lands to cotton cultivation, and within a couple of years all traces of reclamation had vanished and the basins returned to their former waste condition.

It has been already remarked that for reclamation by perennial irrigation it is necessary to have one's water supply ensured throughout the year, and efficient drainage. It is frequently very difficult to obtain water in summer, and, as reclamation extends the problem becomes more difficult every day. I see no reason why the supplies needed in summer should not be stored on the lands to be reclaimed. I take as an example the little Borollos, a depression containing 90,000 acres, lying about ·5 metre above mean sea, and separated from the great Borollos by a dyke constructed in 1887. I would divide this area into three basins of 30,000 acres each, and surround one of them by double banks of the following section.

An area of 30,000 acres covers 12 kilometres by 10·5 kilometres, and the dyke would therefore be 45 kilometres long, with a cubic content of 1,960,000 cubic

metres, costing £39,200 as an outside figure, because the area is intersected with old banks, which might be utilised. During flood the water would be allowed to sweep over the area and wash it, while in winter the canals would be tailed into this basin and fill it by the end of April, up to which date there would never be any lack of water. Early in May rice sowing would begin and the water supply would fail everywhere; the reservoir could then be drawn on for water; and since it had been filled to a depth of 1·50 metre, of which ·75 metre might be considered as lost, the remaining ·75 metre would represent $(126{,}000{,}000 \times \cdot 75) = 94{,}500{,}000$ cubic metres, or a discharge of 945,000 cubic metres per twenty-four hours for 100 days. This would suffice for $\left(\frac{945{,}000}{40}\right) = 23{,}600$ acres of summer rice. This summer rice would be worth £70,000. The land cultivated with summer rice would be gradually reclaimed, while the land in the basin itself would become, in the course of seven or eight years, valuable land. One of the other belts might then be turned into a reservoir, and this one planted with cotton.

The wash of the waves on the dykes would be guarded against by a growth of bulrushes and 'birrîya' weeds; the staking of the dykes would cost £50 a kilometre, or £2250 altogether. If these were not sufficient, masonry revetments would be necessary for the dykes on the south and east sides of the lakes, as the force of the north-west winds is always felt there. Such revetments would be similar to those in the more important basins of Upper Egypt, and would cost £400 per kilometre of dyke."

Mr E. W. Foster, C.M.G., the Managing Director of the Behera Company, tried one of these basin reservoirs in salted clay land and kept it under water for four years. The water was always too salted for irrigation purposes, but the land inside the basin was so improved that it was sold at £40 per acre. The reclamation, of course, would depend on the quantity of water available in flood and winter.

91. Mansûr Shakûr Pasha on Land Reclamation.

" It should be prefaced that the land forming the object of the following remarks generally lies at or below R.L. 1·50, or in parts of the country where efficient free flow drainage is difficult to obtain, as in the Sharkia Province.

The two principal methods in use are:—

(*a*) Reclamation by basin flooding, and

(*b*) Reclamation by draining and washing the land, and by growing 'reclamation' crops.

(*a*) The former method, that of basin flooding, consists in levelling the land and dividing it up into basins of 500 to 1000 acres each. These basins are filled with water when the supply is sufficient and emptied at intervals into drains which carry off the water by free flow. Injurious salts are removed by the water flowing off the land, and a beneficial deposit of silt is left. This method is comparatively slow, requiring from three to five years in order to become effectual; in practice it can be applied successfully only over large areas, and cannot therefore be adopted except in the case of large landowners or companies.

(*b*) The second method consists essentially in washing the land, by allowing water to percolate through it into drains cut at comparatively short distances apart.

The water is conveyed through these drains either by free flow into a main public drain, or is pumped out of them into the main public drain. The washing is followed by amelioration crops, and in the third year the land is generally sweet enough to grow cotton.

It is evident that in this method drainage plays an all-important part. As mentioned above, the land is generally below R.L. 1·50 metre and the level in the public drains is seldom more than 0·50 metre below the land, for these drains are usually filled by the better-class lands through which they pass before reaching the waste lands.

This difference of level of 0·50 metre was at one time thought sufficient, and a system of drains was designed for the land under treatment. This design was based on a fall of about 0·10 metre per kilometre, for, theoretically, this was more than sufficient. In some cases it was found possible, after treating the land for several years in this manner, to grow a poor rice crop; but in most cases the land did not progress at all. Experience, however, gradually pointed to the necessity of establishing pumping installations to help in the drainage of such lands. It was not, however, until recent years that this means was systematically tried. The results have been more than satisfactory. Once, however, that this method began to be adopted, it was found that the fall given to drains, and based on theoretical formulæ, was quite inadequate.

The pump-well would be dry while, a few hundred metres away, the drains were full of water and the land was saturated. Now, there is no more striking instance of how little theory can be relied upon than in this question of drainage by pumping, nor how necessary it is to have recourse to experience in order to obtain a satisfactory result. When we think of it, this is really quite natural, for the usual formulæ relating to the flow of water are based on experiments carried out under perfect conditions. Whereas there is a notable difference between the results obtained when experimenting with a trough whose sides are smooth and regular, and the results given when water is run through a cut in the ground half filled with weeds, and where it is necessary for the flow of water itself to keep the channel open and carry away clods of earth that fall into the drain from its sides or are pushed in by the feet of the peasant or his animals.

In such a case experience shows that, for small drains the fall must be from 40 centimetres to 50 centimetres per kilometre— that is, no less than eight to ten times the fall considered theoretically sufficient. In the writer's opinion, it is this fact which is the secret of the success of those who understood it and put it into effect.

Now that experience has taught us how a drainage scheme should be designed, it is easy to understand that for land of the kind under consideration, it is necessary to erect pumping installations to lift the drainage water into the public drains, at any rate until the Government can lower the water level in these drains to at least 3 metres below land level.

As a concrete case, let us take an estate of, say, 2000 acres, assuming that it is more or less of rectangular form and that a public drain runs on one side of it.

In designing our drainage scheme let us begin at the corner marked A. In order effectually to drain the land, some agriculturists consider it necessary that the water-table should be 1·50 metres below land level. This view is not shared by all authorities, as in some cases 0·75 metre is considered sufficient. We shall therefore take an intermediate level of 1 metre below land level.

It is usual to make the tertiary drains, marked *a* on plan, 40 to 50 metres apart, and give them a bed width of ·25 metre. It is also advisable that these drains should not be more than 150 to 200 metres in length. In this way an area of 1½ to 2 acres is enclosed between two drains. These drains empty into the secondary drains (*b*), ·40 metre wide and 1·30 metres deep, which in their turn empty into

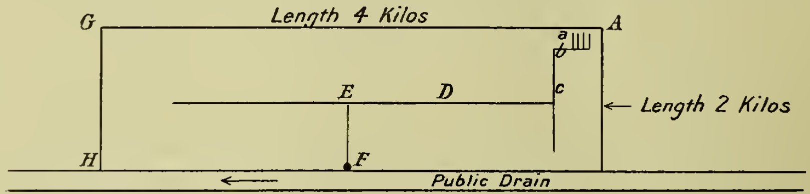


FIG. 36.

the primary drain (*c*), ·60 metre wide and 1·80 metres deep. These last flow into the main drains (D), ·80 metre wide and 2·50 metres deep, which unite at E and empty into the pump-well F.

To fix the depth of the pump-well, it is necessary to work up to it from the small drains *a*. The following diagram shows how this is done, and it is found that the well has to be 3·40 metres below land level.

It is evident therefore that nowhere in Lower Egypt can this method be applied at present without pumping the drainage water. If the position of the estate shown above was such that the public drain ran along the end of the estate from G to H, it is obvious that the main drain D would be longer and consequently

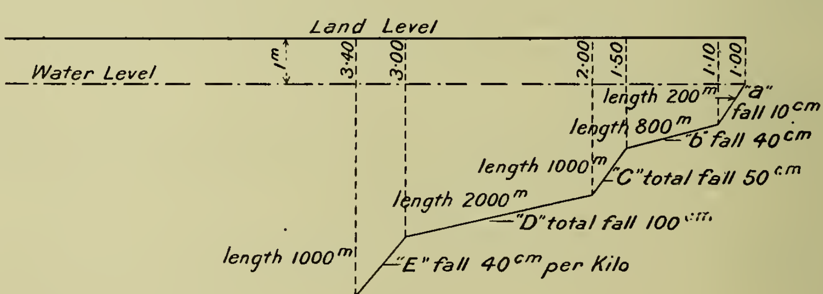


FIG. 37.

the total fall greater. The depth therefore from which the water would have to be pumped would be greater than that given in the above example. The expense of running an installation, such as the above, when applied to an estate of from 1000 to 4000 acres need not exceed £·30 per acre per annum, which is quite a small sum when it is considered that it is possible thereby to give the land as advantageous a system of drainage as if it were in the Menufia province.

It is probable that, had these principles been known and understood earlier, there would have been fewer reclamation failures in Egypt. The writer also considers that the special method herein advocated is one that will restore confidence in the business of land reclamation, and prove invaluable in the treatment of the large areas of Government lands still unreclaimed."

92. **Mr Hood on Land Reclamation.**—The following note has been

Plan of Drains.

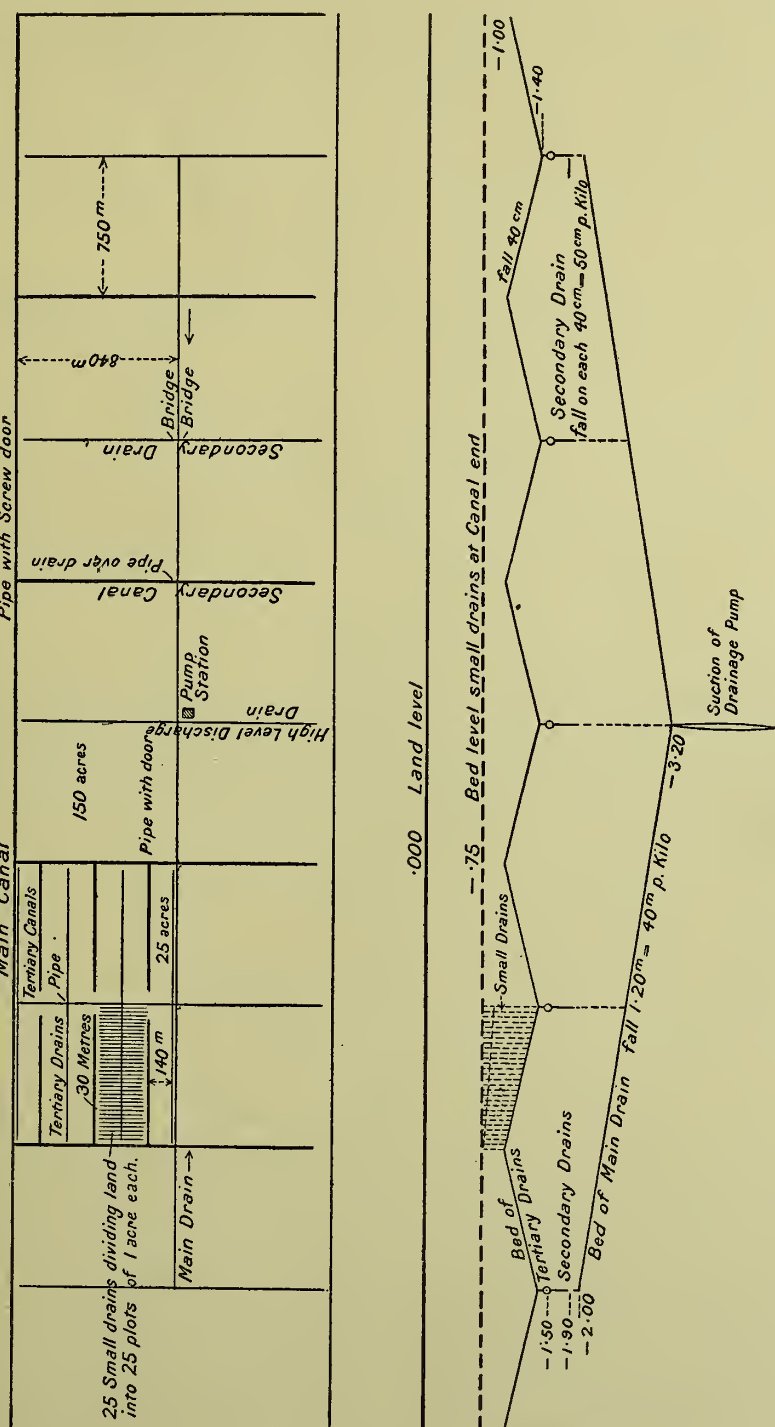


FIG. 38.—Section of Drains.

kindly written for us by Mr T. Hood, the capable manager of the Gharbia Land Company, and refers to land in Eastern Gharbia, where so far irrigation and drainage have been satisfactory, provided pumps are used for draining :—

" *Canalisation.*—It is recommended to cut up the land into plots of 1 to 2 acres. The smaller the plot the less generally will be the cost of levelling,

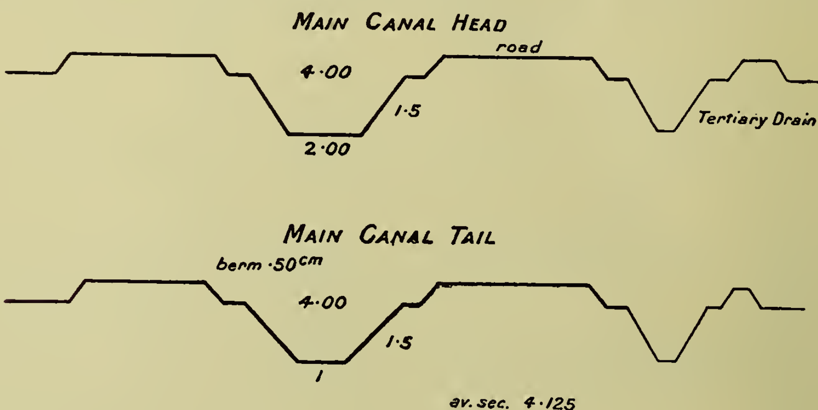


FIG. 39.

each plot being, if possible, levelled into itself, and the closer the small drains the quicker the land will sweeten. I have shown, in fig. 38, plots of 140 × 30 metres = 1 acre each. As the land gets sweet, every alternate drain may be filled in, and if these are first cleaned to a narrow bottom section, and 30 or

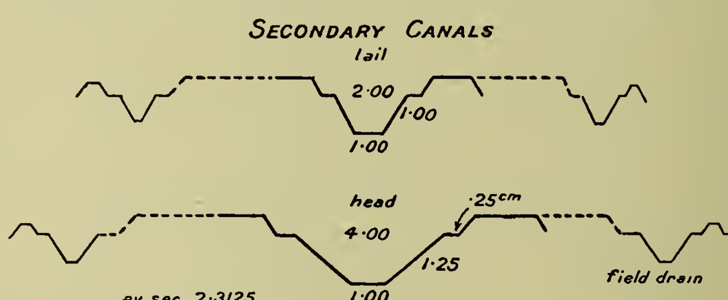


FIG. 40.

40 centimetres depth of cotton stick put in the bottom before filling in, they will continue to act as drains, becoming in fact 'land drains' as extensively made in Essex. In clay land especially, close drains should be put in. It is presumed the drainage will have to be pumped, and the system of narrow drains with an average bed slope of 50 centimetres per kilometre has been evolved. It was found that a smaller sloped drain gets constantly held up with silt and weeds, and by cattle treading in them. The deep main drain also serves as a collecting reservoir when the pump is stopped for any reason. In sandy soil it may not be advisable to excavate the main drain to its full depth in the first year, and the final depth can be given when the banks get set.

The pump will be placed towards the lowest part of the land and may discharge direct into a Government drain or into a high-level main discharging into a

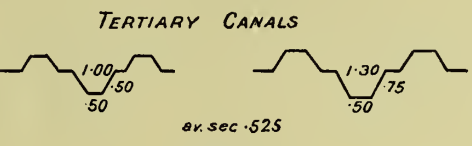


FIG. 41.

Government drain. A high-level drain may save a long length of deep pump drain, and has the advantage that the silt scoured from the pump drain is not discharged

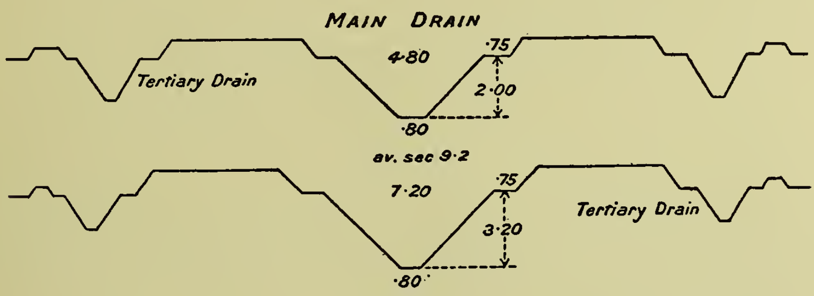


FIG. 42.

into the Government drains but is deposited in the high-level drain which can be cleaned from time to time.

The time taken to reclaim land will be governed greatly by the amount of irrigation water available. The canals shown are for 25 cubic metres per acre per

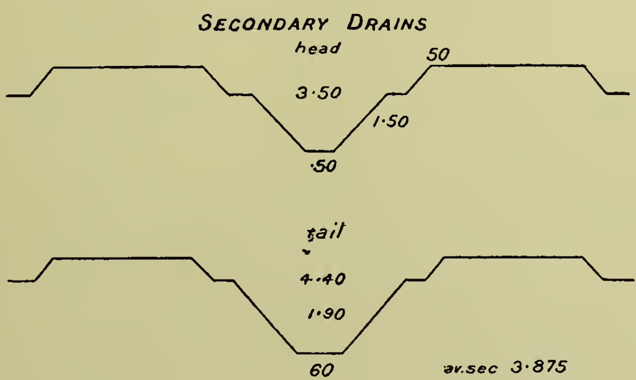


FIG. 43.

twenty-four hours over the whole area in summer, and in Nile and winter the amount of water used will be regulated by the capacity of the drainage pumps. These should be capable of dealing with 35 cubic metres per acre per twenty-four hours over the whole area. Inlet pipes with doors should be placed at the heads of all canals, as complete control of water is essential where land is pump drained. All obstructions to drainage should be avoided, and bridges in place of pipes

adopted where roads cross the larger drains, and canals either syphoned under or carried well over drains rather than drains syphoned under canals. Roads between

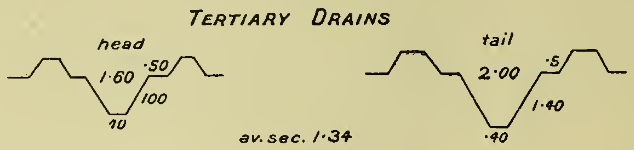


Fig. 44.

the small plots should be made between two tertiary canals rather than between two drains, to prevent choking the drains by cattle crossing. Where tertiary canals

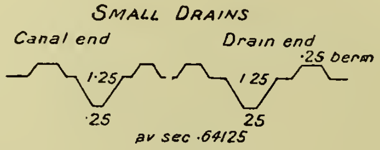


Fig. 45.

have to carry water past low land to water higher land, small infiltration drains should be cut along the top of the plots, leaving a gap of some 2 metres for the

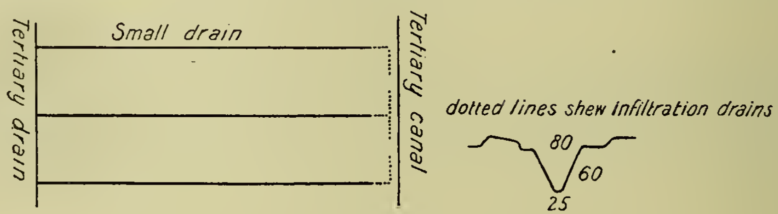


Fig. 46.

irrigation of the plot. In very sandy soil these infiltration drains may be necessary along all tertiary canals.

Levelling.—This varies with every piece of land. Some land requires almost no expenditure under this head, while other land may cost over £20 per acre to level.

Buildings.—Towards the coast, where the rainfall is heavy, ezbas should be built of burnt brick. In any case foundations of red brick should be used.

Washing and Preliminary Cultivation.—The land, according to the degree of saltness and the character of the soil, will require to be washed for a varying length of time, after which dinêba, or in sweeter land rice may be grown. When the land gets sweeter, clover is grown, and good clover land will give cotton. The final cost of reclamation will greatly depend on the time required for preliminary cultivation before the land produces paying crops. Cultivation in the reclaiming stages should be very shallow, or the salt will be brought to the top, and the drains should always be kept clean so as to get the full effect of drainage.

Time required.—For a block of 3000 acres five years would be required with good water and drainage. Sandy soil would come quicker, and heavy clay soil would take longer. A good deal depends on the population of the district and whether they are good fellahin or not.

Value—The land at this stage, if in an average situation and with a good population in the vicinity, at present values of cotton, would probably be then worth £50 to £60 per acre, and with continued good farming should increase in value. Much will depend on the water supply. In the above estimates and in those below I have taken it as being free flow. With good drainage and good water *Berea* land should eventually yield as good cotton for the same quality of soil as other districts in the Delta.

Cost—presuming irrigation by free flow—3000 *acres*.

Canalisation—		
Main canal, 7500 × 4·125 metres = 30,937 cubic metres at 15 mill.	£464	
Secondary canals, 6 × 1500 × 2·3125 metres = 21,645 cubic metres at 12 mill.	260	
Tertiary canals, 60 × 740 × ·525 metres = 23,310 cubic metres at 10 mill.	233	
Main drain, 6000 × 9·2 metres = 55,200 cubic metres at 25 mill.	1380	
Secondary drains, 11 × 840 × 3·875 metres = 35,805 cubic metres at 15 mill.	537	
Tertiary drains, 80 × 750 × 1·34 metres = 80,400 cubic metres at 12 mill.	964	
Small drains, 3000 × 130 × ·64125 metres = 250,087 cubic metres at 10 mill.	2500	
High-level discharge drain, 4000 cubic metres at 15 mill.	60	
		£6,398
Pipes, regulators, and culverts		1,500
Drainage pumping plant		3,000
Levelling, say, at £5		15,000
Ezbas, 300 houses at £15 (red brick foundations)		4,500
Houses for staff and storehouses		2,000
Cattle and implements		4,500
		£36,898
Staff manager, assistant, clerks, storekeepers, five years	£3750	
Washing: £450 (first year), £450 (second year), £350 (third year), £250 (fourth year), £200 (fifth year)	1700	
Pumping drainage, 4½ years at 25 piastres per acre	3375	
Cultivation: £1450 (second year), £2000 (third year)	3450	
Drain clearances: £750 (first year), £750 (second year), £600 (third year)	2100	
Sundries	2500	
		16,875
		£53,773
Receipts for the fourth and fifth years are not credited, and are set against taxes and expenses of cultivation in the fourth and fifth years, clearances, etc. They will vary with every piece of land. £17 per acre		£53,773"

93. **Audebeau Bey on Land Reclamation.**—The following notes on land reclamation have been kindly supplied by M. Audebeau Bey, Chief Engineer of the State Domains Administration, an expert in irrigation and drainage.

"*Well-salted Lands.*—These should be reclaimed by letting the water filter through the soil and not by washing.

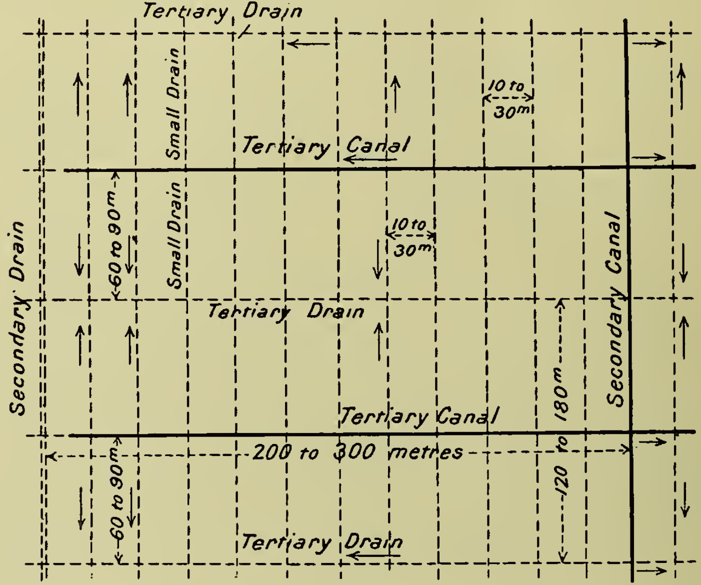
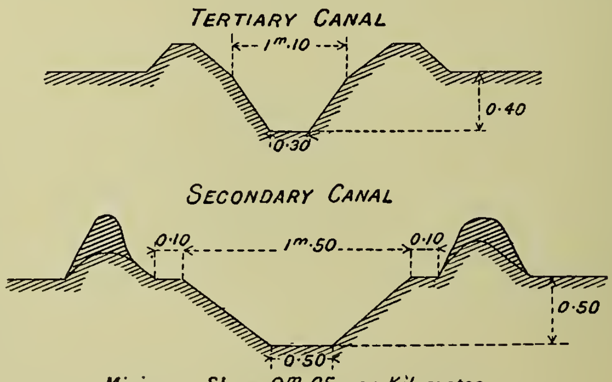


Fig. 47.

The secondary drains should be from 200 to 300 metres apart, and the tertiary drains from 120 to 180 metres. Between two tertiary drains should be a tertiary



(Spoil to be everywhere as high as it can be to economise ground.)

Fig. 48.

canal. The small drains flowing into the tertiary drains should be from 10 to 30 metres apart according to the stiffness of the salted clay to be reclaimed.

Figs. 47 to 51 give a plan of the ground to be reclaimed, showing positions of canals and drains, and sections of canals and drains. A secondary drain should have its bed 20 centimetres below that of a tertiary drain, and the tertiary drain 20 centimetres below that of a small drain.

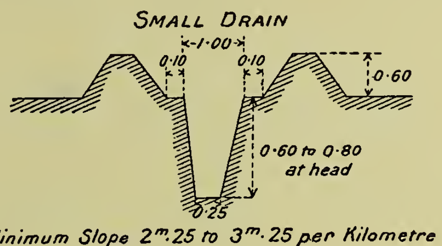


FIG. 49.

The primary drains should have a slope of ·20 metre per kilometre, and the secondary drains of ·40 metre per kilometre. The slopes of the sides of the drains should be 1/1 or 1½/1, according to the nature of the soil.

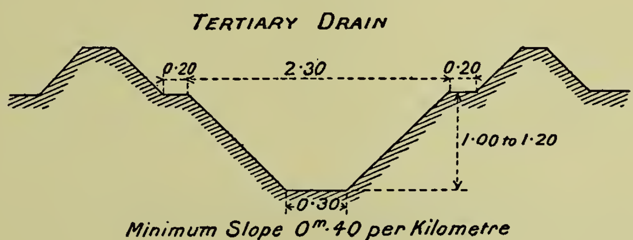


FIG. 50.

When levelling land to be reclaimed, never allow any part of it to be above the level of the water in the section.

The cost of the canals and drains comes to between £3 and £4·5 per acre, and

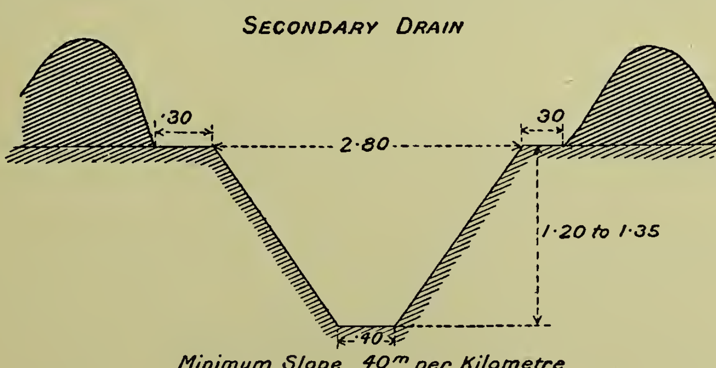


FIG. 51.

to this has to be added from £1 to £1·3 per acre for supervision during reclamation. If the drainage has to be pumped, the cost of the pumping station has to be added.

Slightly Salted Lands.—These may be reclaimed by surface washing, in basins

of from 4 to 6 acres each, after the accompanying sketch. The slopes and sections of the drains are the same as before. If some part of the land cannot be so reclaimed, a modification of the preceding system can be adopted. If, on the contrary, the lands are capable of being reclaimed in larger basins, the latter may be enlarged, but never to more than 16 acres per basin, but the tertiary drains should never be more than 180 metres apart.

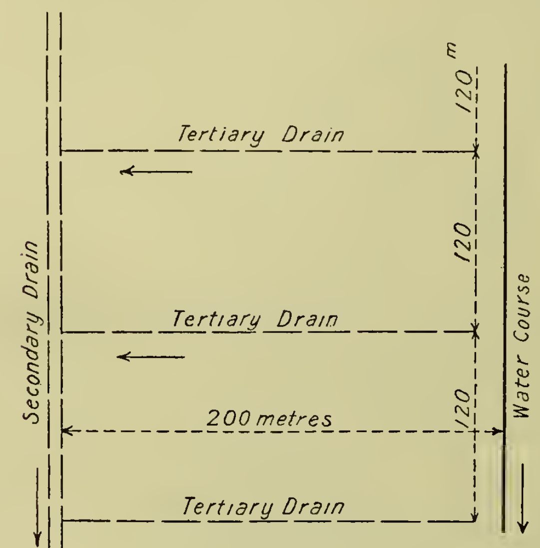


FIG. 52.

The water off such lands should be changed every six days if possible.

Pumped Drainage.—Do not employ large pumps serving large areas; it is better to multiply the number of small pumps and work by a central station with electricity.

Increase the slope of the drains in their last kilometre as they approach the pump, and give the last kilometre of the main drain leading to the pump a greatly enlarged section, thus converting it into a regulating basin.

Do not suddenly lower the water in any drain, or you will bring down the sides. It is on this account, among others, that a large section of the main drain near the pump is of value.

Pipe Drainage.—In 1902–03 an area of about 30 acres was reclaimed by pipe drainage in the following manner:—

The land was surrounded by a dyke 1 metre in height. 12-centimetre clay pipes were laid 70 centimetres below the surface, and 12 metres apart. The length of each line of pipes was 290 metres. They tailed into a collector drain 1·10 metres below the surface and led off to a pump.

Water to a depth of 50 centimetres was held over the land from the 2nd September 1902 to the 17th January 1903, or for 137 days.

Before reclamation began, the quantity of sodium chloride in the soil at the surface was 14·3 per cent., and from 10 to 60 centimetres it was 4·7 per cent. On the 26th February it was found that the quantity at the surface was 3·1 per cent., from 15 to 30 centimetres down it was 2·0 per cent., and from 30 to 45 centimetres down 4·2 per cent.

The water pumped from the drain had the following number of kilograms of sodium chloride per cubic metre of water.

4th October	31 kilograms	15th November	14 kilograms
15th October	27 ,,	22nd November	12 ,,
5th November	25 ,,	11th January	6·2 ,,

There were 3267 tons of salt removed from the 30 acres. The cost of putting in the pipes was £12 per acre, and of pumping £1 per acre. These would be considerably higher to-day.

No levelling of the land was needed, and none was done.

In 1903 the 30 acres of land were sown with cotton and yielded between 2·90 and 4·2 kantars per acre."

94. **Nourisson Bey on Land Reclamation.**—Programme of land reclamation by M. Nourisson Bey, one of Cairo's well-known agricultural experts:—

"For the reclamation of 3000 acres of waste land in the Berea, composed of moderately dense clay soil, fairly level, without mounds, but gently undulating, with sand heaps 50 centimetres to 1 metre in height, and in part covered with brushwood.

The reclamation will take six years; and the property should be divided into six sections of 500 acres each, with a village of fifty huts and one magazine for each section.

The drainage will be ensured by small drains 80 centimetres deep, from 100 to 150 metres long as a maximum, 40 metres apart, and tailing into a main drain increasing in size and calculated for a daily discharge of 30 cubic metres per acre, and with a slope of 40 centimetres per kilometre.

The land will be levelled by means of steam ploughs and the native kassabia.

After levelling, the land will be put under water. There will be no surface washing through openings in the banks, but all the water will have to filter through the land into the drains.

Surface washings will be given in flood time and during winter when water is plentiful.

Excepting very salted lands and dense clay soils, if land has been uninterruptedly under from 10 to 20 centimetres of water for three months, with the water filtering through the soil into the 80-centimetre drains, it is sufficiently reclaimed to produce dinêba and rice, and then clover.

If the land is not sufficiently reclaimed owing to insufficiency of water or dirtiness of drains, the work must be begun again next year. In the calculations I assume that half the area will be sufficiently reclaimed in the first year.

Under ordinary conditions, well-washed land which produces good clover can be rented for £3 per acre if the drainage is attended to.

This is the order of the operations:—

First Year—

A. A survey of the lands, with plans of the roads, canals, and drains.

B. Lining out and executing the above. Building all necessary constructions; foundations of burnt bricks, and rest with sun-dried.

C. On the first section to be reclaimed, the brushwood will be cleared, the land ploughed and levelled, digging of minor drains and watercourses, and putting on all the water available.

D. Erection of the pumping station, consisting of two Diesel motors of 60-h.p. with two pumps of 24 inches (for 90,000 cubic metres to be raised 3½ metres in eighteen hours), of which half to be erected at once.

Second Year—

Cultivation of dinêba or rice and then clover on half of the first section, and second washing of the other half.

Construction of a fifty-house village on section No. 2, and its treatment as above.

Third Year—

The same for the third section.

Renting 250 acres of section No. 1 at £3.

Cultivation of dinêba and rice on 250 acres of section No. 1, and of 250 acres of No. 2. The second washing of the other 250 acres of No. 2.

Fourth Year—

Section No. 4 taken in hand and treated as above.

Renting 250 acres of No. 1 at £3·50.
" 250 " No. 1 " £3·00.
" 250 " No. 2 " £3·00.

Erecting the second engine and pump.

Fifth Year—

Section No. 5 taken up and treated at above.

Renting 250 acres of No. 1 at £4·0.
" 250 " No. 1 " £3·5.
" 250 " No. 2 " £3·5.
" 250 " No. 2 " £3·0.
" 250 " No. 3 " £3·0.

Sixth Year—

Section No. 6 taken up and treated as before.

Renting 500 acres of No. 1 at £4·0.
" 250 " No. 2 at £4·0.
" 500 " Nos. 2 and 3 at £3·5.
" 500 " Nos. 3 and 4 " £3·0.

The reclamation works being completed, the cost works out as follows :—

Purchase of 3000 acres at £10		£30,000
Buildings of Central Administration		3,000
Pumping station		3,500
Roads, canals, and drains		7,500
Levelling with steam ploughs and reclaiming		9,000
Oxen for supplementary work		3,000
Feeding animals and labour		6,000
General expenses		12,000
Taxes		3,000
300 houses for fellahin at £20		6,000
Six magazines at £250		1,500
Tools and plant		8,000
Cost of washing		1,000
Interest on money		10,000
Total		£103,500
Deduct:		
Rents	£13,000	
Sale of oxen and plant	2,500	
		£15,500
Net Total		£88,000

or about £29 per acre, including £10 per acre for land purchase.

If the work is carried out in four years instead of six, with extra speed, the saving will represent £1 per acre. This is not to be recommended, as the great thing is to secure good fellahin, and this is slow work in the Berea. To have men round you who are able to rent your land is a prime necessity. The lands now should be in a condition to be rented at an average rental of £4 per acre.

Deduct from the rental:

Taxes at	£·20 per acre.
General expenses at	£·50 "
Proportion of buildings at 10 per cent. at .	£·40 "
or,	£1·10 per acre.

This leaves you £2·90 net per acre.

Capitalising at 16½ years' purchase, we arrive at a value of £45 per acre.

We should then have a profit of £16 per acre."

95. **Mr Hicks Paull on Land Reclamation.**—The following communication was kindly sent us by Mr Hicks Paull, the well-known Alexandrian land expert. He is very emphatic about the necessity of deep drainage as you approach the pump, so that the furthest parts of the estate might be well drained.

"Before describing how best to reclaim 3000 acres of salt land in Lower Egypt and to estimate its cost, certain conditions must be laid down, as the amount of capital and time required depends on cost of levelling, necessary means of transport, and population of the surrounding district.

For the purpose of this article it is understood that levelling is not to exceed £8 per acre and that there is a reasonable means of transport.

It is also understood that the plot of land selected adjoins cultivated land on at least one side, and that a Government drain can be connected to the land without having to obtain a 'taradi' (written permission) from adjoining owners.

To reclaim such a piece of land successfully one of two conditions must be complied with:—

1. That there is a reasonable supply of water and that summer rotations allow of rice cultivation.

2. That if rice rotations cannot be permitted in summer, a full supply of water is allowed during the winter months for washing.

Failure must result when an attempt is made to reclaim such a large area of salt land, supplied with irrigation water from a canal, subject to rotations for cotton cultivation (six days' irrigation, twelve days closed) in summer and closed during two months in winter for clearance.

Personally, I consider that a full supply of water for winter washing is more advantageous than an indifferent supply of summer water for rice cultivation.

Certainly with winter washing the cost of reclamation can be reduced, as there is usually a loss of £1 per acre on rice grown as a reclamation crop, not to mention the cost of ploughing after rice, which often equals 10s. per acre.

As nearly all the remaining 'boor' land (uncultivated land) in Lower Egypt is low, it is presumed that artificial drainage will be necessary, and for that reason a private drain connecting with the Government drain is essential.

To obtain the result given in this article, the land should be taken in hand as

early in the year as possible, so as to allow of drains being made, drainage installations erected, and villages for workmen and tenants built before the next Nile, when washing should be commenced on any levelled area.

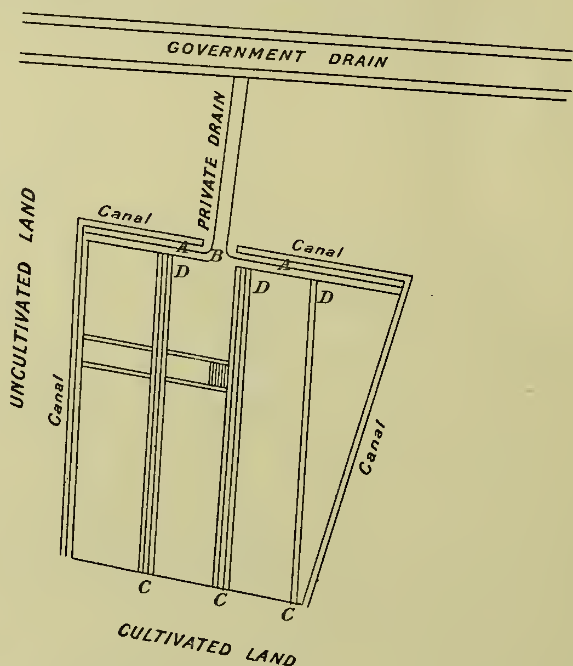


FIG. 53.

For artificial drainage special types of drains are necessary which provide for very heavy slopes and narrow beds.

In this way the drainage flows at a high velocity and prevents the growth of weeds.

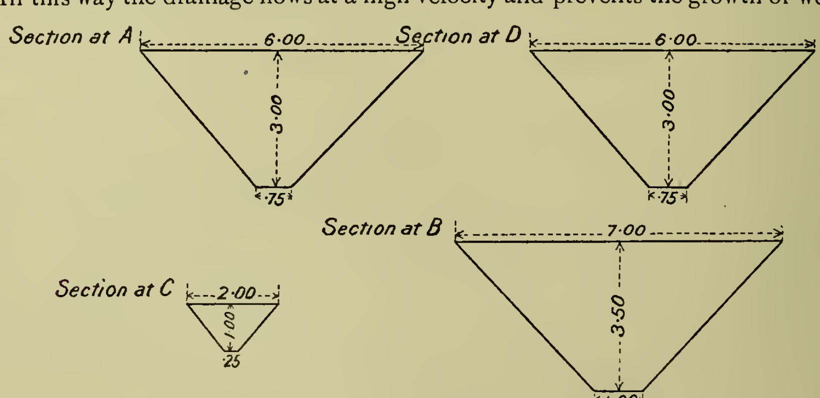


FIG. 54.

Fig. 53 shows the system of drains and canals recommended.

Fig. 54 gives the sections of the drains shown on the plan, with the dimensions which have been found the most suitable for rapid reclamation.

It is strongly recommended to construct canals on boundaries where possible, especially on north and west owing to 'blowing' dust.

I have seen landowners abandon reclamation solely because it was found impossible to keep main drains open.

With canals on the boundaries it is possible to flood an area from which dust blows during the winter months, and thus prevent all trouble.

Experience has proved the open system of drains preferable to other systems for Egypt.

Owing to the flatness of Egypt, pipe draining is never really successful without artificial drainage as well; and once artificial drainage is introduced, pipe drainage seems unnecessary.

Drain sections can only be decided on after the nature of the subsoil has been ascertained.

The heavy black soil of North Gharbia and the light soil found near the deserts will stand very stiff slopes.

In other parts where 'safra' soil or sand is found, the question of slopes is more difficult, and it is generally found advisable not to complete the main drains in the first year.

The cost of constructing main drains, hoshay drains, and field drains, together with the necessary canals, and to erect drainage pumps capable of discharging 30 cubic metres (tons) of drainage per acre daily is (approximately) £2, 15s. 0d. per acre for large areas.

It should be mentioned that steam engines are unsuitable for drainage installations owing to canals being closed for clearances and to rotations in summer.

A drainage installation must generally be erected at the west point, and canals bringing water to the site must pass through salt land for some years.

To use salt water in boilers for even a few days does serious damage, and for a month spells disaster.

For the drainage of 3000 acres pumps are required equal to a discharge of 90,000 cubic metres (tons), and two 18-inch pumps with explosive engines of 40-b.h.p. will be found suitable.

These pumps will only be in full work during the Nile flood from September to December, and afterwards one pump will generally be sufficient.

Winter washing does not require heavy pumping, and if 10 cubic metres (tons) per acre is used daily, it is most satisfactory.

The cost of pumping drainage must be arranged on a basis to show a profit in years to come, so that should the land be sold in small lots the proprietors could arrange to have the drainage pumped by contract.

With this in view 8s. per acre has been found a suitable charge to make, and all land sales should be subject to such a tax.

Should the Government carry out a scheme to render artificial drainage unnecessary, the drainage tax would not be payable.

To make reclamation attractive to investors, cheap land must be obtainable, and even then a long wait must result before interest on capital can be paid.

However, land reclamation in Egypt is sure, and good profits without risk can be anticipated as long as cotton remains at 15 dollars or over.

To carry out the reclamation of 3000 acres as sketched in this article, six or seven years would be necessary and the cost would be from £20 to £23 per acre.

Two tables are given, one showing the expenditure and the other the approximate results in revenues to be anticipated by reclaiming 500 acres each year.

TABLE 210.—EXPENDITURE ON LAND RECLAMATION.

	1.	2.	3.	4.	5.	6.	7.	8.
	£	£	£	£	£	£	£	£
Cost of salt land, 3000 acres at £5 . .	15,000							
Land tax	60	60	60	300	300	450	600	1500
Drains and canals, and drainage installation .	2,000	3,000	2,000	1,250				
Buildings, 300 houses for tenants at £30 .	2,000	1,500	1,500	1,500	1500	1500		
Manager's house, stores, and stables . .	700	1,000	500					
Working drainage pumps	200	500	700	900	1200	1200	500	
Levelling, including cost of animals and engines	6,000	3,600	3,600	3,600	3600	3600	3600	
Cultivation and sundries, including management and wages.	2,000	2,500	2,500	2,500	2000	1500	500	
	27,960	12,160	10,860	10,050	8600	7750	5200	1500

Note.—After the sixth year certain charges would be payable from revenue, and for that reason rather less capital is necessary.

TABLE 211.—REVENUE FROM LAND RECLAMATION.

	New Land reclaimed Yearly.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
	acres	£	£	£	£	£	£	£	£	£	£	£	£	£
1	500	...	...	250	500	1000	1500	2000	2250	2250	2,250	2,250	2,250	2,250
2	500	...	...	...	250	500	1000	1500	2000	2250	2,250	2,250	2,250	2,250
3	500	...	...	...	...	250	500	1000	1500	2000	2,250	2,250	2,250	2,250
4	500	...	...	...	...	...	250	500	1000	1500	2,000	2,250	2,250	2,250
5	500	...	...	...	...	...	...	250	500	1000	1,500	2,000	2,250	2,250
6	500	...	...	...	...	...	...	...	250	500	1,000	1,500	2,000	2,250
	3000	...	...	250	750	1750	3250	5250	7500	9500	11,250	12,500	13,250	13,500

An estate reclaimed on this system should find a ready buyer at £50 per acre, or if broken up and sold in small plots by instalments a slightly higher price might be anticipated."

96. **Mr E. Crewe on Land Reclamation.**—Mr Crewe, Manager of the Land Allotment Company, has kindly sent us the following note on the

Scale (approx.) $\frac{1}{35,000}$.

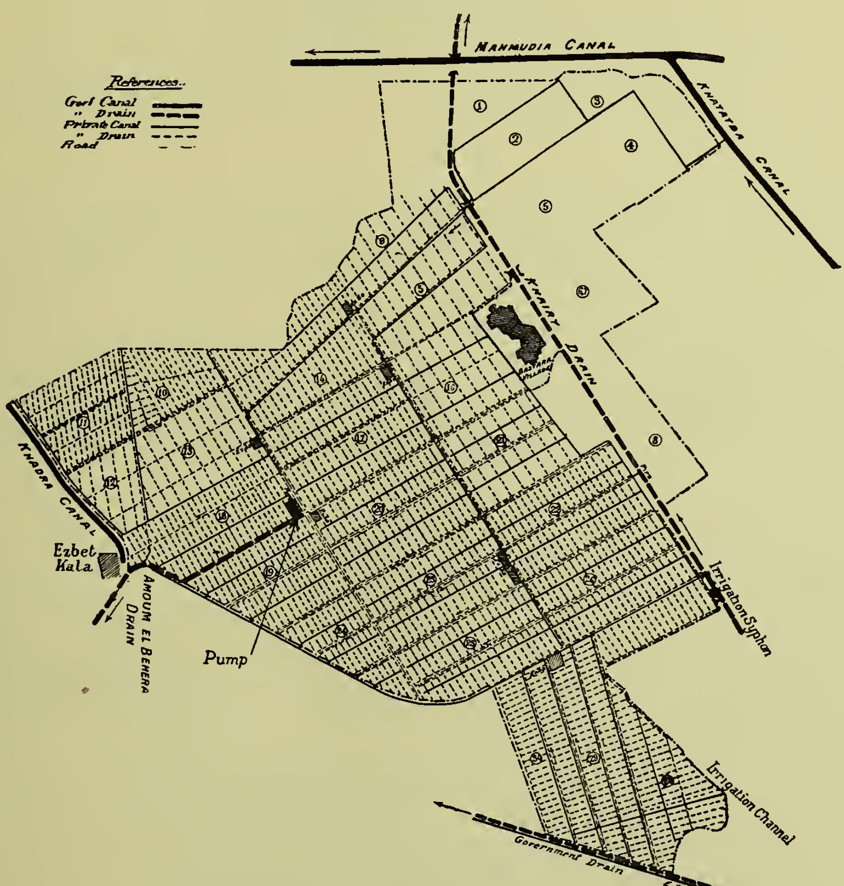


FIG. 55.—Plan of Bastara Estate.

reclamation of one of the properties of the Company in Behera, where water for rice is very scarce, and where the reclamation of the dense clay soil has been consequently tedious and slow:—

"When first the property was purchased reclamation had been taken in hand to a certain extent by the previous owner, and only on a small portion of the estate had much levelling to be done, but the Company had to open drains and remodel the irrigation channels on the whole of the property.

In the first instance, entirely free flow drainage was depended upon; but owing to the annual rise in the level of the Government Drain, the Company decided, in 1911, to pump practically the whole drainage of the estate.

Before installing the drainage pump the estate had been divided up into plots of 70 to 80 acres. Each plot was levelled with cattle, and alternate watercourses and collector drains were dug, with small land drains every 50, or in some cases, 100 metres apart, dividing the plots into small holdings of roughly 2 acres each, and discharging into feeder drains, which in their turn fed the main drains discharging through pipes into the Public Government drains.

In 1911 we erected a machine to pump the drainage at a cost of:—

22-inch Sulzer low-pressure turbine pump worked by a 45-h.p. Garrett superheated steam engine	£902
Buildings, foundations, etc.	297
	£1199

or under £1 per acre.

As we found that the distance between the land drains of 50 or 100 metres did not give the best results, we experimented with drains only 25 metres apart; and as this gave good and quick results, we have now, over practically the whole property, got our land drains only 25 metres apart.

A matter which has greatly retarded the quick reclamation of the property is that we can obtain permission to sow rice only once in three years, and that on 250 acres; consequently, a backward piece of land has always to wait for two years, with only winter washing, before it can be sown with rice a second time.

As a typical cost of reclamation under such conditions, plot 17 (see fig. 55) is taken:—

PLOT NO. 17. AREA 80 ACRES. ANNUAL TAX £0·360 PER ACRE.

Sections of Drains.

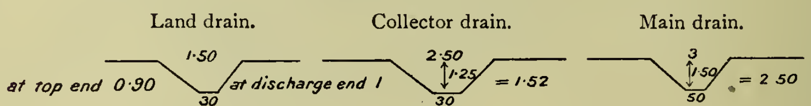


FIG. 56.

Estimate of Cost of Drains and Watercourses.

Land Drains (*every* 25 *metres*).	
Slope 10 centimetres per 100 metres.	
100 × 90 = 9000 at P.T. 1 per cubic metre = . . .	£90·000
Collector Drains.	
Slope 20 centimetres in 700 metres.	
700 × 4 × 1·52 = 4256 at P.T. 1 per cubic metre . . .	42·560
Main Drains.	
Slope 30 centimetres per kilometre.	
2 × 400 × 2·50 = 2000 at P.T. 1·5 „ „ . . .	30·000
Watercourses.	
2 × 700 × 1·30 = 1820 at P.T. 1 „ „ . . .	18·200
	£180·760

or say £2·260 per acre.

		Expenditure per acre.	Profit per acre.
1. Cost of drains and watercourses		£2·260	
2. Proportion cost pumping installation		1·000	
3. Levelling		1·400	
To the above must be added :—			
4. Three years' tax during unproductive state		1·080	
5. Proportion administrative expenses for three years		·930	
6. Proportion construction ezbas, dawar		1·000	
7. Three years' drainage clearances at P.T. 22 per acre per annum		·660	
CROPS.			
1906. Nothing. Winter washing		·100	
1907. Rice, loss on crop per acre		1·530	
1908. Clover. Cost sowing	£1·300		
Value crop	1·000		
		·300	
1909. Leased to tenants			£3·500
1910. „ „			3·500
1911. Rice. Profit on cultivation			2·260
1912. Cotton in partnership, followed by Helba			3·200
		£10·260	£12·460"

97. **Mr Lang-Anderson on Lake Abukir Reclamation.**—This was the first serious work undertaken in land reclamation, and after some years' effort and failure, Mr Lang-Anderson hit on the true method of ensuring success. Once the true method of reclamation was found, and the Government allowed the drainage to be taken into Lake Mareotis, whose artificial water surface lay 2 metres below that of Abukir, success was assured to the enterprise. Owing to the generally sandy nature of the soil, the reclamation of the lands followed so quickly that many companies thought that all soils could be as readily worked, and in the clay soils which constitute the Delta as a rule there were bitter disappointments; but to-day we all understand that we must go slowly in the clays. This property, lying below sea-level in the bed of an old salt lake, has the beds of its drains in such extraordinarily salted land that weeds grow with difficulty, and so the drains can generally dispense with the steep slopes imperative elsewhere. The amount of water available makes reclamation work a successful or unsuccessful undertaking. There is no more any experimental work to be done. The foundation is sure. The following selections are taken from a paper written by Mr Lang-Anderson, and kindly sent us by him :—

" Land reclamation in Egypt is usually a three-years' process. The salt land (and all uncultivated land is salt) has to be washed, then ploughed, and in many

cases levelled. Inferior crops are then grown, and gradually the land becomes fit to produce cotton. The whole of the block to be reclaimed is not taken up at once. Canals which would serve for a cultivated area requiring an ordinary supply of irrigation water would be insufficient for the same area whilst undergoing the process of washing to eliminate salt, and similarly with drains. Cattle have to be purchased, villages built, and labour found. Any sudden demand for labour and cattle would be difficult to satisfy without upsetting market rates. Population has to be attracted to settle on the lands when reclaimed. Success will attend gradual expansion more readily than efforts on too ambitious a scale, which would result in excessive cost, with more land taken up than could be judiciously handled. The cost of reclamation may be taken roughly as £20 per acre.

In March 1887 a concession of Lake Abukir was granted by the Egyptian Government to the late Mr William Grant, who, with the assistance of a London syndicate, afterwards the Abukir Company, Ltd., headed by the late Mr Samuel Gurney Sheppard, immediately began the work of reclamation. In the terms of the concession, main canals and drains had to be dug, and large drainage pumps installed. Under the able direction of Mr H. G. Sheppard, as resident engineer, all this work was accomplished in eighteen months, and, after examination, passed by a Government Commission.

The agricultural development only became possible after the main works were completed, and the system of reclamation was, from the first, initiated by Mr R. Lang-Anderson, and has been carried out by him since that time. This system is now generally adopted for all similar lands in Lower Egypt.

According to the concession, drainage pumps had to be installed, and two 48-inch centrifugal pumps, driven by direct-acting compound engines, were erected by Messrs J. & H. Gwynne. These pumps together delivered 350 cubic metres of drainage water per minute into Abukir Bay. The Government afterwards allowed syphons to be made under the Mahmudia Canal, and by these drainage now flows to Lake Mareotis, the surface of which is 2 metres lower than Abukir, thus affording a better drainage system than could be obtained by pumping.

Lake Abukir was the smallest of all the lakes, and contains an area of 30,000 acres. The dimensions are:—

12½ kilometres in length (east to west), and 9½ kilometres in width (north to south).

The bed of the lake was nearly a dead level, 1 metre below sea, rising by a gentle slope to R.L. – 0·50 on the west and east margins. Abukir was not a permanent lake. Drainage from adjoining cultivated land on the east, and winter rainfall, averaging 20 centimetres per annum, caused an accumulation of water in the lower parts to a depth of 30 centimetres in winter, but this was evaporated during the summer, leaving a crust of white salt, nearly pure sodium chloride, a few centimetres thick. Clearly marked traces of old water channels and remains of foundations of houses confirm historical proof that Abukir was cultivated, probably until the middle of the eighteenth century, when an irruption of the sea destroyed the cultivation.

The main drains and canals divided the land into six kisms of about 5000 acres each. The kisms are named north, south, central, etc. Where possible the main canals and drains are given a slope of $\frac{1}{10,000}$, so that reasonable

velocity can be given to the flow of the water. Extreme flatness of the land or adverse rise at times necessitates making slopes of only $\frac{1}{20,000}$, the minimum permissible.

Main canals are calculated to supply, when running full to ground-level, 30 cubic metres per acre per day. At High Nile, when water is abundant, and washing new land demands greater supplies, the canals can carry water above the level of the berms, so increasing supply.

Drains should have the same sectional area as the corresponding canals, but with greater depth. Although drainage water is only one-third of the amount of irrigation water used for crops, drains, to be efficient, must only carry water in one-third or half their depth. If run full to ground-level, they are useless. Hence it arises that a drain must be as large as a corresponding canal, although carrying

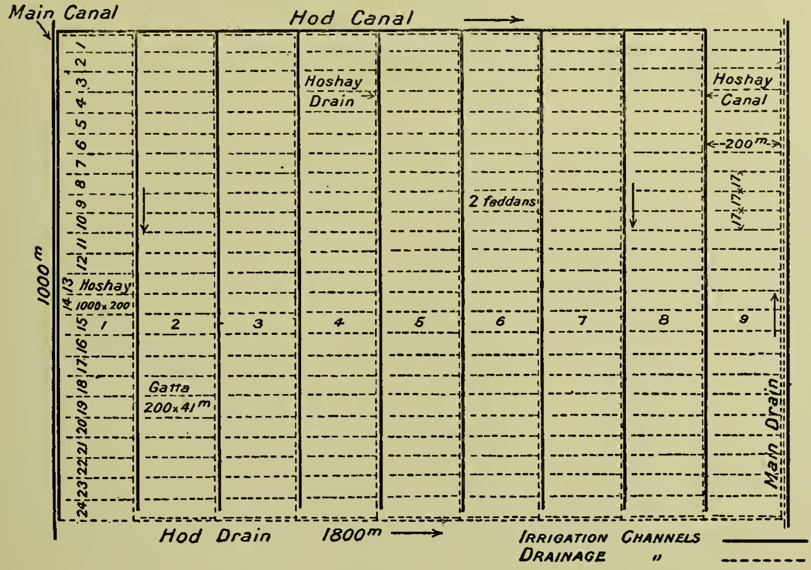


FIG. 57.

one-third of the water. During the early stages of washing land, the proportion of drainage is very much more than one-third.

The secondary system of canals and drains divides the land into hods, a typical one being 1600 metres long by 1000 metres wide. The area of such a hod is 381 acres, an acre being 4200 square metres. The channels are designed to carry 50 cubic metres per day. The minimum slope of these secondary channels should be $\frac{1}{10,000}$. If attainable, more slope is preferable. A kism does not require to be irrigated all at one time, but a hod often does: hence the greater allowance of water per acre. Hods are numbered by Roman numerals.

The hods are divided into eight hoshays, 1000 metres by 200 metres. At the side of the hoshay there is a canal and drain, with a road between.

The hoshays are divided into 24 gattas, 200 metres by 41 metres.

The 24 gattas of 41 metres equal 984 metres, whilst the length of the hoshay

is 1000 metres, but 16 metres are occupied by the road, canal, and drain of the hod. The area of a gatta is taken as 2 acres, although actually slightly less. Government land tax is collected on gross area without deduction for roads and drains and canals. Tenants or purchasers must therefore pay for land occupied by these necessary works which serve their lands.

The gattas have only small drains, ·80 to 1 metre deep, ·25 wide at the bottom, and 1·00 to 1·25 metres at the top. No permanent irrigation channels for gattas are needed, as these are made each time the land is ploughed, by a wide plough rut.

A plan of a typical hod is given to show the canalisation system.

Plots are all numbered according to the direction of the flow of irrigation water.

Thus on a lease or sale contract, North Kism, Hod III., Hoshay 3, Gattas 5–8, or N. III., 3 $\frac{5-8}{}$ indicates exactly the plot of land, and as each gatta is 2 acres, a stranger could at once identify the 8 acres in question.

The canalisation being completed, the process of washing begins. The gatta has a bank all round it from the soil thrown up in making its drains. Water is admitted from the hoshay canal, and the plot flooded 10 centimetres deep. The water filters through, and enters the bottom of the drain, dissolving out the salt. Washing goes on from October till April,* when water is abundant, and hardly needed for crops, and the plots are never dried. The amount of water which percolates through depends entirely on the porosity of the soil. If water is shut off from a gatta flooded 10 centimetres deep, the surface will sometimes be dry in twenty-four hours, *i.e.* 420 metres per feddan have percolated. Such a very porous soil would wash very quickly. On some impervious soils the water will not disappear for a week. In such a case, when it is seen that a soil is so retentive, another drain should at once be made up the middle of the gatta.

Three or at most four men should attend to the washing of a hod. They have to see that the gattas are kept full and not allowed to overflow, that banks are not broken by wave action during wind, and that any soil slipping into the drains is at once removed. Inattention to these details loses time in reclamation, and a few neglected gattas scattered here and there prevent a hoshay being let in its entirety on a desired rotation.

Washing being completed in April, the land is dried off and ploughed. It is then sown in dinêba (*Panicum crus galli*), a species of millet which grows as a weed in rice fields. Either consumed green or made into hay, it is good fodder for cattle. Rice can also be grown, but it is more susceptible to salt, requires more constant water, and is more expensive to grow, and if it does not mature to a crop is worth nothing. When there is any doubt about land being sweet enough, it is best to grow dinêba. It affords a perfect analysis of a whole plot. From the appearance of the different patches, prediction could be made of the amount of residual salt remaining if subjected to chemical analysis.

In October, when dinêba or rice have shown satisfactory growth, berseem, *i.e.* Egyptian clover (*Trifolium Alexandrinum*), is sown. If dinêba has not succeeded, it is pure waste of time and of expensive seed to sow berseem. Washing is there-

* In other estates, as a rule, there is a winter closure of the Government canals of about six weeks.—AUTHORS.

fore resumed for another season, and berseem sowing postponed. Good berseem crop is the goal of the land reclaimer. When that can be grown, all other crops will follow and the land may be let at good rents. It is useless to let partially reclaimed land at low rents to natives, in the hope that they will complete reclamation. They will only cultivate the best parts, and the rest, instead of advancing, will revert. The whole must then be taken back and done over again, with loss of time and money.

As reclamation advances, houses have to be built. The usual Egyptian beehive-shaped mud hut of the fellah, of sun-dried brick, is quite unsuitable for Abukir, and proved an entire failure. Bricks made of soil still salt will not dry properly; nor will they stand the rain and damp of the coast zone. Red burnt brick, made on the spot, is therefore used.

As soon as a hod is taken up for reclamation, a village (Arabic 'ezba') is begun. The houses are 3·5 metres by 3·5 metres inside measurements by 3 metres high. Two ranges of ten or twelve houses are placed parallel, about 20 metres apart. Walls at back and front constitute, with these houses, a court for cattle.

The inner lines of houses are not completed at first, the room being carried on brick columns to form an open shed for cattle. The ploughmen and labourers engaged on a hod occupy the outer houses, the cattle the inner sheds. When reclamation of a hod is completed and the land let, men and cattle move to a new hod, and are succeeded by tenants. The front wall of the cattle sheds and the partition walls are then built in to form houses corresponding to the outer ones. A small enclosure wall is built for each two rooms to afford privacy. A tenant of 8 acres is allowed two rooms and his small court without paying rent. The two rooms and enclosure cost £32.

Under the most favourable circumstances, with porous soil, easily washed land has been let twelve months after it was first taken in hand, but this is exceptional, two, and more often three, years being required to bring it to letting condition.

Land having been got into condition for letting—and the point of having it really fit for tenants cannot be too strongly enforced—the next thing is to find tenants. On Abukir the demand for land is keen, and deposits of £1 and £2 per acre are freely offered by fellahin desirous to become tenants. Leases are for three years. The average holding is 8 acres. A tenant should, if possible, have two buffalo cows to plough his land, turn his water-lifting wheel, and at the same time give a valuable milk yield and manure.

Cotton is the crop on which a proprietor depends for his rent, and supervision must be exercised during its growth and picking. On Abukir, cotton always follows berseem. Like all leguminous plants, berseem absorbs nitrogen from the air by bacteria in nodules on its roots, thus greatly enriching a soil naturally deficient in this element. It also adds humus, and, as it is largely fed off on the ground, the animal droppings have decided manurial value. The growing of berseem is encouraged as much as possible. Berseem, which is ploughed up in March for cotton, has yielded three cuttings. What is left for seeding, until June, yields five cuttings. A great deal of berseem is carted into Alexandria for sale at from 6s. to 10s. a cart-load, and this is a large source of revenue to tenants. Nearly every horse in Alexandria is sent out to

eat berseem in the fields for three or four weeks, at a daily charge of 1 P.T. to 2 P.T. (2½d. to 5d.).

A tenant puts half his land under cotton crop. He ploughs up berseem land in March, giving it three ploughings and a ridging up. The native plough is used. It is merely a one-tine grubber, and does not turn the sod, but it is efficient, and in the end, by dint of three ploughings, has done good work. So near the sea, cotton plants do not attain the large dimensions found in the older and richer provinces, farther south.

Manure is rarely used for cotton. The farmyard manure produced is devoted by the native to his maize crop. Nitrate of soda when used is apt to produce excessive growth of leaf and wood and retard ripening, but this action is somewhat checked by the simultaneous use of superphosphates.

Tenants.—A typical tenant should have 8 acres of land, own two buffalo cows (worth £30 to £40), a donkey (£3), a wooden plough, and a hoe or two, with some small implements (£2). If on good land, an industrious tenant's account would be:—

Rent, 8 acres at £6 . .	£48	4 acres cotton, at 3 kantars, 12 kantars, at £4¼ . .	£51
Cotton seed, ½ ardeb . .	·500	4 acres maize, at 4 ardebs, 16 ards, at P.T. 120, half consumed . . .	9·600
Picking cotton worm . .	·270	6 acres berseem, one cutting sold on 2 acres . .	3·600
Drain cleaning . . .	·400	2 acres wheat, 4 ards, at P.T. 150, half consumed . .	6·000
Cotton watchmen . .	·500	Milk of two buffaloes . .	24·000
Village watchmen . .	·400		
Sundry seeds and expenses .	4·130		
	£54·200		
Profit	40·000		
	£94·200		£94·200

If a tenant picks his own cotton worm and cleans his own drains, he is not charged for these outlays.

He has more wheat or maize than he and his family can eat, and he has half of it to sell, and berseem and straw feed his cattle. He can sell his milk to a European Laiterie at Ezbet Khurshed, or to local men who go round the ezbas collecting it, at 1s. per gallon, or 30 centimes per litre. The fellah lives frugally on bread made of maize, wheat, or barley, or all mixed together, beans with a little oil, a few onions, or cucumbers. All of these things he can grow for himself, and he has chickens and milk. His clothing is not an expensive item. A fellah is paid £1 per month wages, and can support himself and family comfortably on that sum.

Tenants' accounts are settled once a year—in December, after he has delivered his cotton. A note is made out of rent and other debits, and of the value of the cotton sold. If the tenant has not cleared his rent, he either pays something from other sources of revenue, or the balance is carried over. In the case of credit balances the tenant receives half the amount in cash, the remainder standing at his credit; but in no case does the Company retain more than one-third of the ensuing year's rent."

The following figure is taken from the second edition of this work, and is part of a paper by Mr H. G. Sheppard, entitled "The Reclamation of Lake Abukir," *Min. Proc. Inst. Civil Engineers*, London, vol. ci.

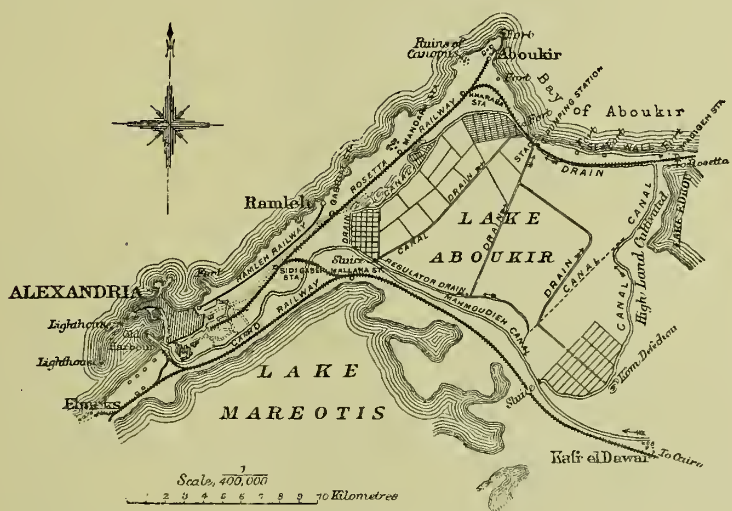


FIG. 58.

98. **The Wadi Tumilât Reclamation.**—The Wadi Tumilât estate, west of Ismailia, lies in one block some 20 kilometres long and 4 broad, covers 20,000 acres, and had three-quarters of its area turned into a swamp by the high-lying Ismailia Canal, running along it at a high level in sandy soil, and filtering freely into it. In old days it was irrigated by about 1000 wells in the fields, constructed by Mohamed Ali. This estate is a good example of the inutility of draining a long swamped area by means of one long drain down the middle of it with a single tail pump. The drain and pump were first put in hand in 1892, but thoroughly taken in hand in 1899. The high-lying land, 5000 acres in all, independent of drainage, has been so much improved since 1899, that it could be let to-day for £25,000 net per annum. The gross receipts of the estate in 1911 were £48,500, with an expenditure on pumping and maintenance of £21,000, leaving a net profit of £27,500, or little more than the land not needing drainage could bring in itself. We have left out of the count £2500 spent on raising land. Out of the 20,000 acres, 13,000 were let in 1911, and of these 4000 were under dwarf papyrus and 1000 under rice. The only really reclaimed swamp lies within 4 or 5 kilometres of the pump. Now, if this area of 15,000 acres needing drainage were divided into five zones of 3000 acres apiece, and the drains led to as many pumps, the net revenue of the whole estate would find itself doubled. We advised the construction of five pumps at the beginning of the undertaking, and we do so again now. One long

drain and one pump have done so little in twenty years that the scientific method of pumping by zones might be given a trial.

Here are the results for 1911 :—

The revenue was £48,500, of which £46,700 were rents, palm-trees £400, and petty items £1400.

The expenditure was £23,500, of which £2500 (items 11 and 12) were capital, leaving £21,000 for maintenance.

Details of Expenditure.

(1)	Salaries of employees	£3,138
(2)	Kassassin pumping station	5,545
(3)	Taxes on land and palm-trees	8,038
(4)	Canal and drain clearance	1,956
(5)	Petty expenses and travelling allowance	483
(6)	Cultivating gardens	216
(7)	House and office at Kassassin	940
(8)	Repairs to pumps	572
(9)	Installation of telephone	0
(10)	House and office at Abbassa	6
(11)	Reclaiming land *	1,563
(12)	Laying a Decauville line *	1,049
	Total	£23,506

As the accounts are carefully kept and published, we give the details of expenditure :—

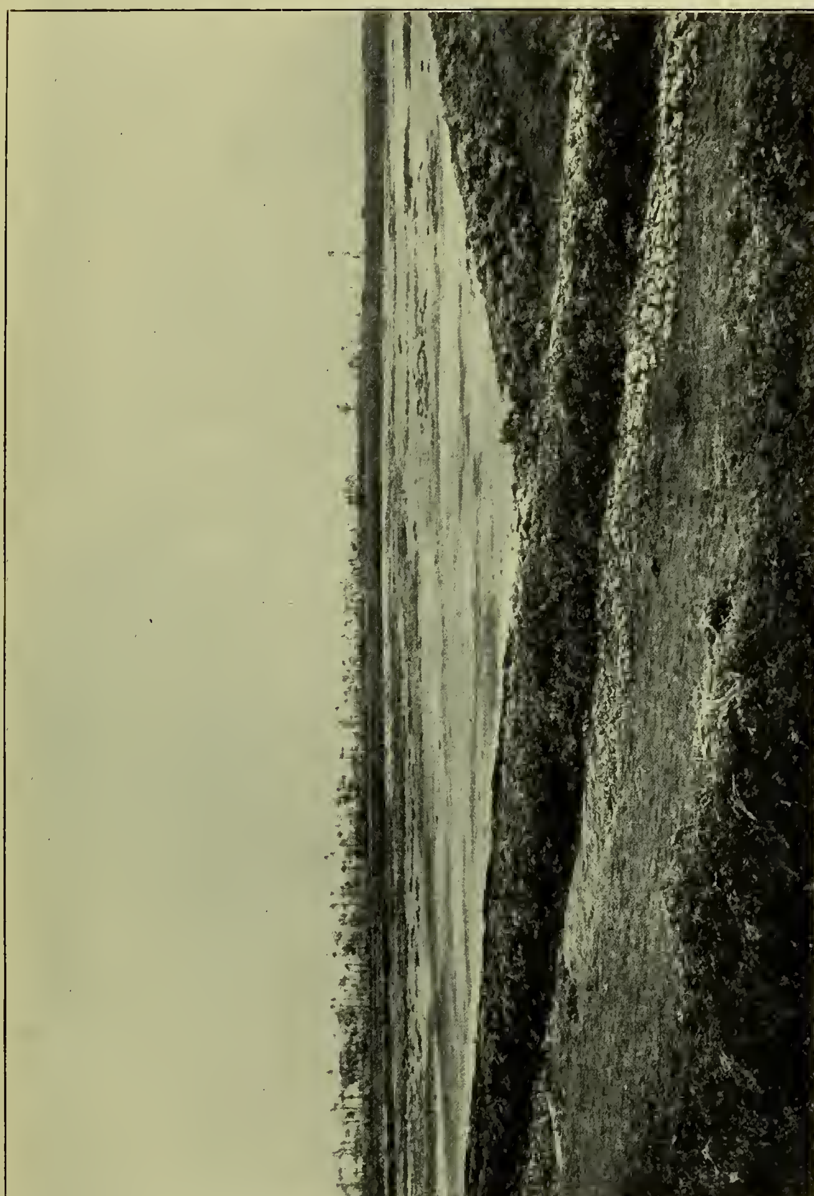
The working of the pumping station, which cost this year £5545, is made up as follows :—

Salaries	£989
Coal	4208
Stores	298
Petty Expenses	50
	£5545

The duty of these pumps is as follows :—

The area rented which was drained by the pumps is	16,082	acres.
The total quantity of water pumped is	63,160,176	cubic metres.
The average discharge per twenty-four hours	173,040	,,
The average discharge per second	2	,,
The quantity of water per acre per twenty-four hours	10·7	,,
The total quantity of coal consumed is	2,318	tons.
The average daily mean lift is	2·6	metres.
The consumption of coal per water horse-power	3·77	kgs.
The consumption of coal per million cubic metres lifted	36·716	tons.
The cost per million cubic metres lifted	£88	
Cost per acre of area protected by installation	£ 0·344	

* By raising the level of the land with soil from the neighbouring deserts.



Land to be reclaimed.

PLATE XXXV.

Salted Land, Lower Egypt.

To face page 505.

Clearances.

Works on the drains and canals of the estate and their respective rates are the following:—

	Kilometres.	Rate per kilometre long.
Clearance of hod drains	50·477	4·950
Clearance of main canals	23·042	4·600
Clearance of hosha drains	199·787	2·900
Clearance of hosha miskas	202·243	2·900
Cutting weeds 'Boot' in hod drains and canals .	24·070	1·500
Cutting weeds 'Hagna' in hod drains and canals .	19·605	1·000
Cutting weeds in hosha drains and miskas . .	22·910	0·750

Digging 1710 cubic metres of new drains at the rate of £0·012 per cubic metre.

99. **Reclamation Works in Italy.**—The following quotations are from the second edition:—

These notes were made in 1892 during a three weeks' study of irrigation and reclamation in the valley of the Po. They contain much information about very extensive drainage and reclamation works which may be of practical use in this country, as the mouth of the Po in summer has a climate not very different from that of the sea-board of the Delta.

"From Ferrara eastwards to the Adriatic the land is very low-lying, but very carefully cultivated. The principal crop is hemp, with rows of mulberry trees and vines at intervals of about 50 metres. The manure which is applied to the fields is principally made of bones and blood and the chippings of horse hoofs. Where the spring level is ·75 metre below the surface of the ground the crops are excellent. If the spring level is under ·75 metre but over ·25 metre, the land is converted into rich pastures. If it is intended to convert pasture land into arable land, the spring level has to be lowered by drainage cuts and pumping. There is an enormous extent of land just above and below spring level in the valley of the Po, which has been improved and reclaimed by drainage. Some pumps serve 500 acres, some 10,000 acres, while the mean area on a pumping station is 2500. One low-lying tract which I inspected near Porto Maggiore was 33,500 acres in extent and was drained by nine pumping stations. To the east of it lay the 'Bonificazione della Gallare,' of 30,000 acres, drained by one pumping station, while at Codigora I saw the largest pumping station in Italy, which drains 125,000 acres. This last tract, however, was too extensive, and the *most economical area to drain with one pump is* 2500 *acres.* Through the kindness of Mr Borsari, of Porto Maggiore, I have been able to tabulate the cost of reclamation and improvement of 33,500 acres.

TABLE 212.—COMPARATIVE RESULTS OF LAND RECLAMATION AND DRAINAGE IN THE VALLEY OF THE PO NEAR FERRARA.

Name of Commune.	Area in acres.	Water drained off by Pumps, cubic metres per second.	Coal consumed, in tons per annum.	Annual Cost of Maintenance, including Coal, £.	Horse-Power.		Cost of Reclamation Works in £.	Compensation to High Lands, £.	Works benefiting High Lands and Drained Lands alike, Part paid by drained Area, £.	
					Effective.	Indicated.				
1. Benore . .	5,523	2·6	190	480	67	132	17,986	1,258	2,988	Cost of works comes to £3·5 per acre.
2. Cersallo .	1,708	·8	77	208	23	45	5,303	...	676	
3. Bevilacqua .	2,983	1·4	104	320	37	72	9,752	166		
4. Martinella .	5,684	2·4	190	480	68	132	16,002	1,461		
5. Trava . .	1,235	·6	64	188	18	34	5,223			Maintenance charges per annum come to £1 per 10 acres.
6. Benvignante .	5,785	2·7	190	480	66	132	17,233	...	1,501	
7. Sabbiosola .	2,567	1·2	87	224	28	55	8,708	...	1,221	
8. Monte Santo	2,452	1·2	77	208	22	44	7,675	...	2,343	
9. Campo Circo	5,658	2·6	190	480	68	132	16,999	...	2,220	
Total .	33,595	15·5	1,169	3,068	397	778	104,881	2,885	10,949	

£118,715

It will be seen from the table that there are nine pumping stations, while there is one Chief Engineer, Mr Borsari, four Assistant Engineers, and the usual staff of engine-drivers, etc. Mr Borsari informed me that if the drainage area is under 1000 acres in extent, the effect of the drainage is immediately felt, while if the area is 5000 acres it takes two years to appreciate the benefit. I saw the foundation being put in of a new pumping station, and it struck me that if ever similar work was undertaken in Egypt, it would be far better to obtain the services of experienced men from Italy than to employ the first man who offered himself, as is too often done in Egypt. The work under construction was solidly and cheaply designed with a very free use of arches. Nearly all the recent engines and pumps were centrifugal.

The accompanying sketch gives a fair idea of the positions of the pumping stations for the tract of 33,500 acres of land improved by drainage near Porto Maggiore.

The whole of the drainage and pumping has been and is done at the expense of the proprietors. The Government drains are all in embankment.

The River Volano, in high embankment, is one of the drains of the district. The lands are all drained by pumping into it or into one of the other rivers.

Referring to Table 212, it will be seen that the cost of improvement and reclamation of 33,600 acres came to 119,000*l.*, thus made up:—

Earthwork in drains	£29,000	
Masonry	29,000	Masonry costs 90 piastres per cubic metre.
Pumping machinery	26,000	
Compensation	13,000	Earthwork, 2 piastres per cubic metre.
Projects, etc.	5,000	
Contingencies	17,000	
	£119,000	

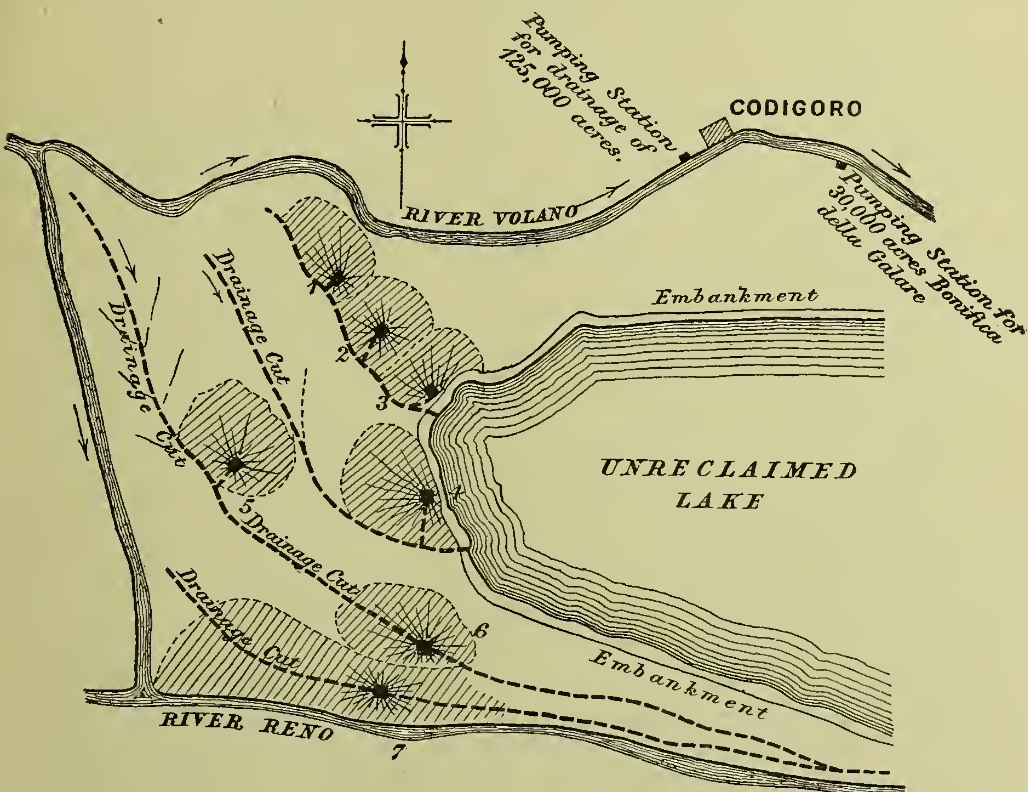


FIG. 59.

The actual net benefit to the lands drained is as follows:—

High land	16	piastres per acre per annum.
Low land	24	,, ,, ,,
Mean	20	,, ,, ,,

So that the net profit on 33,600 acres at 20 piastres per acre per annum is £6720, or 6 per cent. on the money spent, with the assurance that the lands will *not* deteriorate, and as population increases, and silk-worm culture and vines are gradually introduced, the land will take its place as first-class. The best land

east of Ferrara lets at £2·50 per acre per annum, while the lands we are now treating of have been up to the present improved as follows :—

Best land	from	£1·60 to	£1·67	per annum.
„	„	1·50 to	1·60	„
„	„	1·30 to	1·50	„
Reclaimed land	„	·50 to	1·00	„
„	„	·30 to	·75	„

The depth of the drains is so regulated that the lowest-lying land must be ·80 metre above water-level in the drain. It will readily be understood that the larger

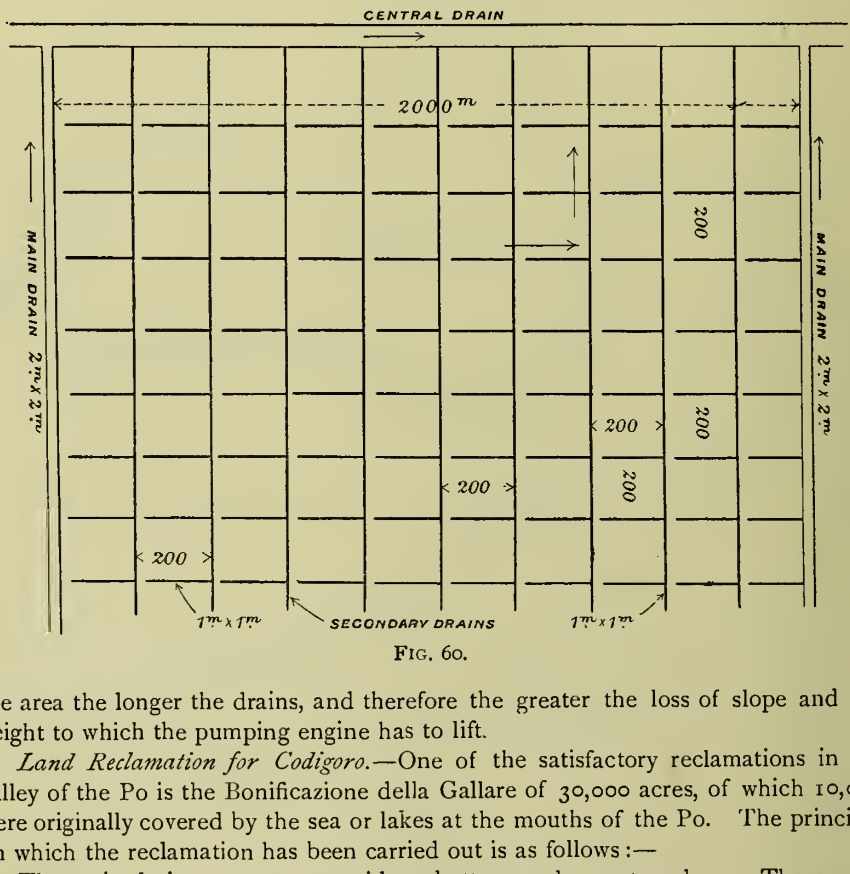


FIG. 60.

the area the longer the drains, and therefore the greater the loss of slope and the height to which the pumping engine has to lift.

Land Reclamation for Codigoro.—One of the satisfactory reclamations in the valley of the Po is the Bonificazione della Gallare of 30,000 acres, of which 10,000 were originally covered by the sea or lakes at the mouths of the Po. The principle on which the reclamation has been carried out is as follows :—

The main drains are 2 metres wide at bottom and 2 metres deep. The central drain increases in section from the head to the pumping station, where it is 20 metres wide and 2 metres deep.

The space between two main drains is divided into spaces of 200 metres square each by secondary drains, as in the sketch. These secondary drains are all 1 metre deep and 1 metre wide at bottom.

Each of these smaller squares of 200 metres × 200 metres is cut by 12 drains (each drain ·25 metre deep and ·25 metre broad) into long strips each 16 metres wide ; so that a cross section of the ground is as in fig. 62.

The land was very well drained and was principally under wheat when I saw it. The wheat as a rule was excellent, but there were extensive tracts of peat soil where the wheat was poor and weeds and reeds abundant.

One of the main difficulties about reclamation is the reluctance of the peasantry to settle in these low lands. Once they can be induced to settle, mulberries and vines follow as a matter of course, and success is assured.

At the pumping station there were two old Dutch pumps (Rade scoop wheels) worked by engines of 400 horse-power, and a 48-inch 'Gwynnes' Invincible pump worked by an 80-horse-power engine. This latter did the whole of the work as a rule. It lifted 1 cubic metre per second 4 metres in height, and gave a constant discharge. After heavy rain all three pumps were worked, and as the lift decreased

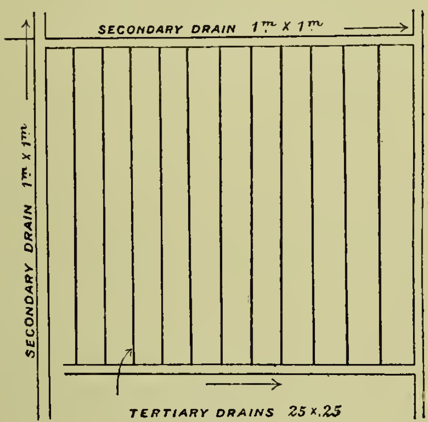


Fig. 61.

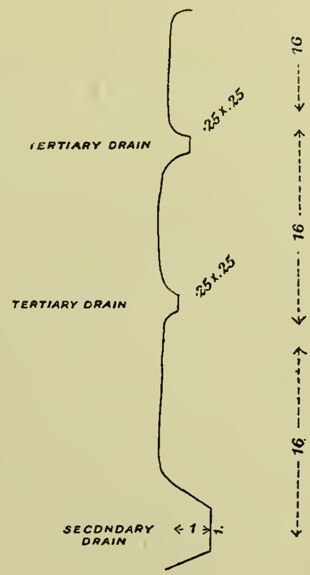


Fig. 62.

considerably they did 8 cubic metres per second between them. The engineer in charge of the station, a Dutchman, was loud in praises of the Invincible pump."

The following is from notes made by K. O. Ghaleb Effendi of the Public Works Department, during a visit he paid the valley of the Po in 1911 :—

The following is the translation of the conclusion of a technical note (dated 15th May 1910) prepared by Chief Engineer Ponti and Civil Engineer Palozzi for the Congress held at Bologna in September 1910 :—

" It is with reason that the province of Ferrara can be considered the classical home of land improvement by drainage, whether this drainage is obtained by gravitation or by pumping. Numerous are the examples of ameliorating the lands from an agricultural and a hygienic point of view by the practical application of hydraulics and mechanics. These examples form a precious practical contribution to the study of the most important and difficult problems relating to land reclamation, such as the separation of the high from the low waters, and the division, more or less, of the large areas into smaller ones, specially in the cases of mechanical drainage.

It is there that the comparison between the conditions of reclamation on the right and those on the left of the Volano is at once evident and already of world-wide fame."

In that part of the Ferrarese territory to the right of the river Volano and extending from the river Primaro to the Adriatic Sea, there is what is known as the Consorzio del Secondo Circondario and the reclaimed areas of Galavrenara e Forcello, Argenta e File, and Longastrino.

The Consorzio del Circondario is divided up. Its whole area is 107,428 acres, of which 44,824 acres are drained by gravitation, 62,168 acres artificially, and 436 acres, or 0·4 per cent., are occupied by the drains. This territory therefore comprises thirteen separate and independent pumping stations for areas ranging from 29,155 acres to 1076 acres.

The Grande Bonifica Ferrarese lies to the left of the Volano and extends to the river Po. It covers 128,972 acres, of which 38,456 acres are high lands and 90,516 acres form the low lands to the east.

It has 520 kilometres of drains, which occupy 1·32 per cent. of its area. The longest distance the water has to travel is 38 kilometres, and its slope in the main drains is ·05 metre per kilometre. With the exception of the small Tenimente Mesola (comprising Benefiche Pescarina and Balanzetta), which is absolutely independent and all by itself as its pumps are worked electrically by long-distance transmission, the Grande Bonifica Ferrarese is drained mechanically by the huge and well-known pumping stations at Codigoro near the Adriatic; the old one for the water coming from the high lands, and the new establishment (that has been working for two years now, though it has not yet been definitively taken over from the contractors) for the low lands.

To my knowledge, this is the only place where large pumping stations versus small ones can be studied with profit, so as to settle once and for all this moot question.*

The Ferrara engineers are still of the opinion that was expressed to Sir William Willcocks in the summer of 1892 (*Egyptian Irrigation*, page 396), that better results are obtained by dividing up the land into sections, each of which having a small adequate pumping station, than by having a large pumping station for the whole territory. A glance at the two last columns of Table 214 seems to confirm this view, though it is difficult to compare the figures and make deductions, as the conditions have not been reduced to the same standard. However, the highest authorities on the matter in Italy wanted the Grande Bonifica Ferrarese to be divided up into several sections.

This division would have upset the existing system of drains designed for one pumping station; from the administrative point of view, and also from the agricultural, it was thought better in this particular case not to change the order of things that had been going on for years and years.

It was deemed wiser to be satisfied with the complete separation of the drainage of the high lands from that of the low lands, and to improve the machinery, etc., of the old establishment.

The following translation of an extract from *Notizie techniche sui consorzi e sulle benefiche Ferraresi* explains the case:—

"To collect and direct on to the pumping station at Codigoro all the drainage

* Here it is, of course, only a question of drainage. The question of escapes for red-water irrigation in flood does not enter here as it does in Egypt.—AUTHORS.

waters from such a large territory has given to this installation, for its size, the pre-eminence in Europe; but it was also one of the reasons of its deficiency. When data were being collected and the new work studied and approved, the 'Commissione Centrale' for the reclamation of lands, the local office of the Genio Civile and of the Consorzio and the Superior Council of Public Works advised the separation of the large territory into two, three, or four separate divisions, with separate pumping stations. These three different methods of dividing the whole area have been put in evidence in the supplementary note of the 12th October 1901 to the preliminary project of the 1st July of the same year, that recommended one main collector at Codigoro. These modifications and the original project have been prepared by the local office of the Genio Civile with the help of the technical one of the Consorzio.

TABLE 213.—CONSORZIO DEL 2 CIRCONDARIO, AREAS OF SUBDIVISIONS.

Name of Section.		Land Levels of Area drained. By Pumps. High.	Mean.	Low.	By Gravitation.	Area drained, in acres. By Pumps.	By Gravitation.	Length of Main Drains, in kilometres. In Area drained by Pumps.	In Area drained by Gravitation.	Discharge of Main Drain, in cubic metres per second.
Stellise	A Scolo Naturale	...	...	...	1·46	...	1,673	...	10·230	5·812
	Bonifica Tersallo	2·43	1·25	0·19	...	1,659	...	1·094	...	0·802
Masi	A Scolo Naturale	...	...	...	2·88	...	8,508	...	19·500	5·738
	Bonifica Denore	2·97	1·44	0·23	...	5,631	...	6·287	...	2·593
Gattola	A Scolo Naturale	...	...	...	2·02	...	5,840	...	2·615 9·346	14·743 4·806
	Bonifica Campocieco	2·26	1·34	0·39	...	5,386	...	1·016	...	2·650
S. Antonino	A Scolo Naturale	...	...	...	2·93	...	20,660	...	...	10·289
	Bonifica Montesanto	2·50	1·93	0·95	...	2,311	...	3·829	...	1·160
Sabbiosola	A Scola Naturale	...	...	...	1·68	...	2,237	...	19·919	4·490
	Bonifica di Sabbiosola	2·38	1·50	0·44	...	2,520	...	3·558	...	1·205
Benvignante	A Scolo Naturale	...	...	...	2·02	...	3,097	...	11·503	5·740
	Bonifica Benvignante	A3·65	1·49	0·50	...	2,451	...	3·505	...	1·490
		B3·77	1·93	0·72	..	3,139	...	5·005	...	1·225
Trava	Bonifica Trava	...	0·73	0·52	...	1,076	...	2·422	...	0·587
Martinella	A Scolo Naturale	...	...	...	1·29	...	2,809	...	10·808	4·020
	Bonifica Martinella	3·46	1·04	0·05	...	5,343	...	4·853	...	2·428
Bovilacqua	Bonifica di Bovilacqua	2·16	0·84	0·10	...	2,892	...	4·286	...	1·400
Gallare e Valle Volta	Bonifica Marozzo	1·00	1·70	2·00	...	29,155	...	10·000	...	9·400
	Bonifica Mazzore	...	...	2·00	...	595	...	0·860	...	0·250
						62,268	44,824			

Total area drained	106,992 acres
Area occupied by drains . . .	435 ,,
Grand Total . . .	107,427 ,,

TABLE 214.—CONSORZIO DEL 2 CIRCONDARIO, DETAILS OF WATER PUMPED.

Name of Zone artificially reclaimed in the Ferrarese Territory.	Area in acres.	Mean Minimum Land Level.	H. W. L. in Main Drain.	Mean Height of Water raised, in metres.	Maximum quantity of Water raised per sec., in cubic metres.	Number of Pumps.	Mean Working Hours per year.	Vertical Shrinking of Land Surface, in metres.	Total Cost of Work per acre, in £.	Total Annual Cost per acre, in £.
Grande Bonificazione (Acque alte)	38,456	−1·00	−2·50	3·00	26·	8	5000	1·60	5·233	0·150
Ferrarese (Acque basse)	90,516	−2·30	−3·70	4·20	36·	5				
Mezzola { Bonifica Pescarina	4,165	−1·22	−1·45	1·52	1·77	2	2500	0·50	...	0·164
Mezzola { ,, Balanzetta	4,463	−1·87	−2·22	2·27	1·10	2	3200	0·20	2·402	0·110
Bonifica Terzallo	1,659	0·19	−1·77	2·14	·80	1	730	0·30	3·863	0·087
,, Donoro	5,631	0·23	−1·55	1·95	2·59	2	800	0·30	4·238	0·094
,, Campociecco	5,386	0·39	−1·67	1·92	2·66	2	800	0·30	4·841	0·060
,, Montesanto	2,311	0·95	−0·43	1·43	1·16	1	730	0·20	3·581	0·061
,, Sabbiosola	2,520	0·44	−1·02	1·76	1·21	1	750	0·20	3·158	0·070
,, Benvignante A	2,451	0·50	−0·88	1·65	1·22	1	800	0·20	2·812	0·058
,, ,, B	3,139	0·72	−1·22	2·00	1·49	1				
,, Trava	1,076	−0·52	−2·25	2·50	·59	1	1290	0·70	5·519	0·174
,, Martinella	5,348	0·05	−2·05	2·10	2·43	2	960	0·60	5·048	0·081
,, Bovilacqua	2,892	−0·10	−1·94	2·00	1·40	1	900	0·40	3·355	0·083
,, Marozzo	29,155	−2·00	−4·00	4·00	10·00	3	1200	0·70	2·593	0·067
,, Mazzore	595	−2·00	−2·70	4·40	·25	1	1000	...	4·536	0·097
Bonifica Galavronara e Forcello	5,203	−0·90	−2·00	2·80	2·70	2	1220	0·65	1·823	0·088
,, Argenta e File	16,286	−1·45	−2·67	3·25	8·00	4	950	1·20	5·108	0·178
,, Longastrino	1,357	−0·70	−1·60	2·00	0·68	1	980	0·20	3·645	0·183

Administrative and economic requirements prevailed over strictly technical ones. A perfect solution of the problem, hydraulically speaking, was given up, and the Consorzio (that had already asked for the concession of doing the work) was instructed to present its own project on the basis of that of the 1st July, with one main drain at Codigoro." . . .

"'Modification No. 1 (*i.e.* dividing the territory into two distinct zones, one for the drainage of the high lands and the other for that of the low ones) was given preference over the other two by the local engineers, who doubted whether a bigger subdivision of the territory recommended in ordinary cases would be advisable and consistent with the pre-existent hydraulic, agricultural, and administrative arrangements.

'The said modification No. 1 consisted in the construction of a new pumping station for the high waters at Tieni (about 10 kilometres U.S. of Codigoro), without having anything to do with the restoration and completion of that existing at Codigoro, which had already been decided upon.

'On the contrary, Signor Pasini proposed that this new pumping station be built at Codigoro, solely for the low waters, keeping for the high ones the old installation restored.

'In this way it was presumed to continue benefiting by the economical advantages of having the unity of direction at Codigoro, of using the escape of the old Goro into the Volano as in the project of 16th December 1903.

'There would be no loss in transporting the pumping station reserved for the

drainage of the high lands, from Tieni to Codigoro ; better still, the height to which waters have to be raised is decreased because the slope of the Volano in flood is ·08 per kilometre, and that of the main drains is ·05 per kilometre.' ". . .

"In 1901–02 the same installation was improved by the addition of a small subsidiary pumping station at Mazzore near Migliaro, for completely drying a chain of small acreage, too distant from Marozzo and slightly more depressed than the other low lands, as it was not convenient for such a minute zone to lower the zero of the project of the whole territory."

The following extracts from articles written by well-known authorities might be of interest. They are from the "Costruttore" (*Trattato Pratico delle Costruzioni Civili*, *Industriali e Publiche*).

"When there exist appreciable differences of level between the various points of the swamp, the area is divided up into separate zones, with the collectors of the drainage waters at unequal levels, so as to reduce as much as possible the height to which it is necessary to elevate the water. . . .

To effect the reclamation—that is, to expel the waters—with the minimum consumption of fuel and money, it is seen that the mechanical question is subordinate to the hydraulic one, inasmuch as this latter has to furnish the necessary elements so that the work of raising the water be the least possible. . . .

As for the height to which water is to be raised, it is advisable to note that it will not be the same on the whole of the zone to be reclaimed, but there will be some parts in which this height will be more and in others where it will be less. Therefore if the areas having different heights to which the water is to be raised are extensive and these heights are also important, it will be convenient to subdivide the total height into several parts ; and, instead of one large installation, to construct several small ones according to the number of subdivisions of the height.

Fuel will only be wasted if employed to raise a certain quantity of water to a height more than is strictly necessary."

100. **The Mosséri System of Drainage.**—This system permits of land reclamation by reducing the quantity of water to be pumped by 66 per cent. The surface waters of irrigation are separated from the water which filters through the soil, whether the water is used for washing land or irrigating a crop. The surface waters, which are two-thirds of the whole, are discharged by free flow into the public drains. The waters which filter through the soil are carried by the drains and pumped up into the public drain, thus giving an economy of pumping of about two-thirds. This system has been given in full detail in two lectures before the Institut Egyptien, published in their *Bulletin*, 6th December 1909 and July 1911, and other publications.

All that is required is to have the water in the public drain from 15 to 20 centimetres below the surface of the ground. The infiltration water flows in drains which are 1·25 to 1·50 metres below the surface and go straight to the pumping infiltration drain. At the pump the depth is from 2·0 to 3·0 metres according to the length of the drain.

The surface water is led across this last infiltration drain by small iron

pipe aqueducts into the surface water drain and so by free flow into the main. The action is simple, economical, and extraordinarily effective. Though looking somewhat complicated on paper, it is easy to execute and follow on the ground. The infiltration water contains over ten times as

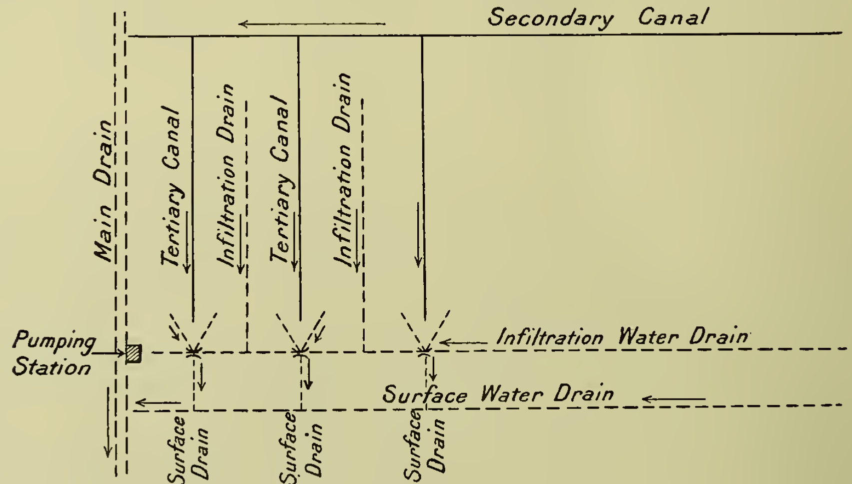


FIG. 63.

much salt as the surface water. We have already stated that the system has been recommended for adoption in the project for draining the salt lands bordering the Mediterranean in France by the authorities appointed to study the question. This system will in time revolutionise land reclamation in clay soils. The cost is so little more than the ordinary system

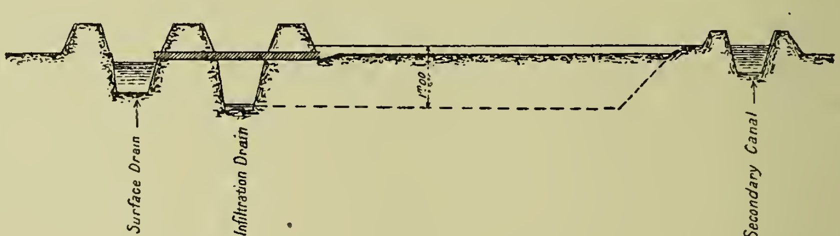


FIG. 64.

that the economies in pumping plant and in interest on money during reclamation make both equal, while the maintenance charges of pumping are reduced by two-thirds.

As already stated in paragraph 74, you enjoy all the benefits of deep infiltration drainage and all the benefits of surface washing with the water leaving its rich deposit on the land. There is no fatigue of the land owing to lack of red water; and there is no going back once you have reclaimed owing to the drains being choked.

100*a*. **Richmond on Land Reclamation.**—The following was kindly sent us by Mr T. S. Richmond, the well-known Alexandrian land expert:—

"For the purpose of this note I have divided the waste lands of Egypt into two classes: (*a*) the Berari or waste and patchily cultivated lands, which extend from the salt lakes on the north to a line on the south approximating with the Kallin-Sherbin railway; (*b*) the beds of the salt lakes.

Mr Lang-Anderson is the principal authority who has fully described the process of reclamation needed for the lakes, and Lake Abukir of to-day is a standing example of what can be done in their development. The writer was for some years in the Abukir Company before he had anything to do with the development of Berari lands, but when he did take up the development of properties in the Berari district he found a very different proposition to that of reclaiming Lake Abukir.

To begin with, the soils are absolutely different.

In Lake Abukir the soil is a light loam which before washing is easily dug with a spade, and the earthwork for canals and drains can be cheaply and quickly done. The Berari lands, on the other hand, consist for the most part of a heavy stiff clay loam, extending to a great depth, which requires much more labour and expense in every way to develop, but when developed is a richer and better crop-yielding soil than the light lake soil. The average cost of reclaiming lake lands is about £12 per acre, but for untouched Berari lands the cost of development is £18 to £25 per acre before reaching the fully developed stage. It is true that some of the Berari lands can be developed almost as cheaply as the lake lands, but those portions are found to consist of lighter land generally above a free-draining sandy subsoil. The lake lands are also, generally speaking, very level from the action of the water before being dried off, so that very little expense is required for levelling, whereas an undeveloped property in the Berari will consist of level land dotted over with *Karduds* or mounds of blown salty dust which have got to be levelled down. The Behera Company, which owns many thousands of acres of *Kardud* lands, have an excellent, cheap, and efficient system of reducing the mounds, which consists of escaping a large quantity of comparatively clear fresh water during the winter on to blocks of a thousand or more acres in extent and allowing the action of the water to dissolve the mounds, which, being heavily impregnated with salt, settle down in an extraordinary manner. This is done on land which they intend to take up in several years' time from the first flooding. After successive washings *en bloc* to reduce the *Karduds*, the land is canalised and developed in the ordinary way. By the action of flooding in this way, which costs practically nothing except for a few earth banks to keep in the water where necessary, the Company reckons to save on an average £6 per acre in levelling on very rough land. The large amount of water used also to a certain extent sweetens the level land, and another important point is that it does away with the necessity of spreading a large quantity of very salty soil over the much less salty level land. Such a process takes time to reduce the *Karduds* and only pays on a large property, where a limited area of land is brought under cultivation each year.

The Berari lands are, on the whole, low-lying, and until the Government drainage project is completed require to be artificially drained by the owners themselves.

Taking a property of 3000 acres of ordinary Berari lands, which has irrigation

facilities and access to a Government drain, the first thing to be done is to choose the most level block of, say, 1000 acres and canalise it. As it is almost certain that steam levelling will be necessary, it is most important to see that the property is properly provided with roads wide enough to carry the engines. All main roads ought to have a top width of at least 5 metres, and the fields should be laid out to facilitate as much as possible the easy moving about of the steam leveller. There is more waste in roads on such a property in comparison to the system of canalisation adopted in reclaiming a lake property where steam tackle is unnecessary, but for the different type of work it will be found to be economical. Until the steam levelling is finished I consider the best size of field is one of 5 acres, *i.e.* 300 metres long by 70 metres wide. After the first year it is generally found advisable to divide the 5-acre field into two fields of $2\frac{1}{2}$ acres each by making a central drain the length of the field, thereby reducing the width of each field to 35 metres. The

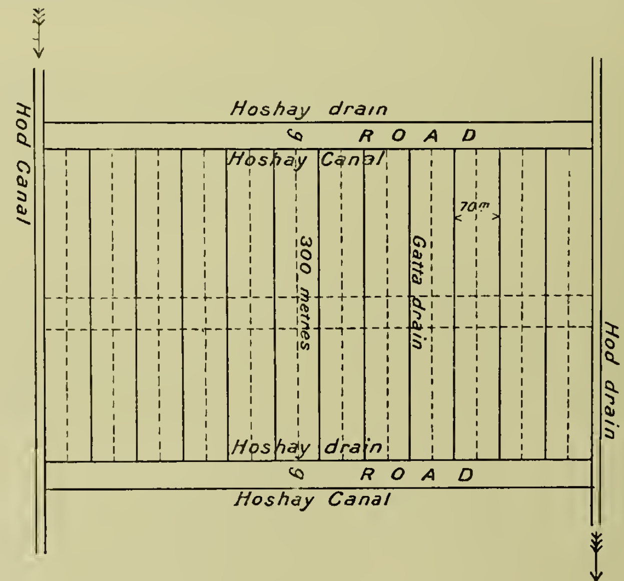


Fig. 64a.

Berari soil, being of an impervious nature, wants close drainage to bring it on rapidly, but a field of less than 35 metres in width is uneconomical.

Those small field drains should be 1 metre deep with a top width of $1\frac{1}{2}$ metres and slope of 1 to 1. A *hoshay* drain passes along one end of the field, and an irrigation canal the other, as in fig. 64a. This canalisation is usually found close enough, but on very impervious soil the 300-metres length can be divided into two by cutting a new *hoshay* drain and canal, thereby reducing the length of the fields to 150 metres, or each field to $1\frac{1}{4}$ acres gross area. The *hoshay* canals and drains vary in size according to the area served, but they must have a big enough section to supply earth for the *hoshay* road. The *hoshay* drains should be at least 1·25 deep.

For pump-drained land the question of the *hod* drains is most important, as they serve as the collector of the *hoshay* drains. The *hod* drains must have a good slope on them. In laying out the property every advantage should be taken of any natural land slope, and the site for the drainage pumping installation should be

most carefully chosen after a close study of the land levels of the property. The most ideal site for the drainage pump is as nearly as possible in the centre of the property, as the leads to the pump are thereby reduced and several drains would converge at the pump. The expense on drain excavation is thereby reduced, and the lift is less and more regular than if the pump is put at one end of the property. When possible a slope of 30 centimetres to the kilometre should be given to the main drains to the pump; and on a 3000-acre block, if the site of the pump is carefully chosen and every advantage taken of the slope of the land, this can usually be accomplished without having the depth of excavation of the main drains at the pump more than 2½ metres.

For a block of 3000 acres it has been found from experience that a drainage pump with a discharge of 1 metre per second is sufficient, and with a first-class installation the annual inclusive working cost is about £·20 per acre.

While the first 1000 acres are being levelled, washed, and drained, the remaining 2000 acres, if covered with *Karduds*, can be flooded as before described until such time as they are required for canalisation purposes. On a large block of land like 3000 acres it is practically never advisable, for several reasons, to try and tackle the whole lot at one time. In the first place, labour in the Berari is not yet too plentiful, and neither is water, and it is most important for anyone taking up land in this district to understand that one's work is absolutely limited by the supply of native labour and by the amount of available water, and that it is a waste of money to canalise land until one is in a position to proceed regularly with its development.

It usually takes four years to fully develop Berari land from the time the canals and drains are first begun, if the work is proceeded with regularly. When fully developed the land is worth an average rental of £5 per acre, more or less according to its situation, and the quality of the soil, with the price of cotton at £3·20 per kantar.

The mode of development is shortly as follows :—

First Year.—Canalisation of the land, building of bridges, sluices, and culverts to get the land ready for washing. Erection of drainage pumping installation and building of houses for the superior staff and sufficient *ezba* accommodation for the workmen, and sheds for the cattle; levelling of the land is also taken in hand. The washing season begins when the flood water begins to clear, as if the flood water is put on to the land when the Nile first comes down it is heavily charged with a fine sediment which tends to reduce the porosity of the soil and retards the washing out of the salts, which is the main object of washing the land.

Second Year.—The land is dried off in April and ploughed and levelled and sown to rice or *dinêba* where it shows signs of sweetening. Land not sufficiently sweet to grow rice is levelled and left fallow until the autumn, when it is again washed. It is unlikely that all the land will come on evenly, owing to variations in soil. The land after rice will give patchy *berseem*. During the summer the drains are cleaned out and additional *ezba* accommodation is built, also magazines for the seed and cattle fodder.

Third Year.—The land is again all ploughed up and sown to rice, and the land which gave patchy *berseem* the second year should now give an even crop and be a great help in keeping down the cost of cattle food. The land not sufficiently advanced for *berseem* the second year will now give a patchy crop.

Fourth Year.—The good *berseem* land is at this stage often let, or cotton is

grown on part of it for the proprietor's account, the balance being left for hay and then ploughed up to be again sown to *berseem* in the autumn. The patchy *berseem* land is generally at this stage put into *dinêba*, which needs less water than rice. In the autumn of this year the whole of the land taken up in the first year will now be ready to lease and be taken off the proprietor's hands by tenants. A sound rotation for the Berari lands at this stage is one-third cotton, one-third rice, and one-third maize, by which method each part of the property is cropped in rice once in three years, which keeps it in good heart.

The rotation would be:—

	Summer.	*Winter.*
First year . . .	rice	*berseem.*
Second „ . . .	maize	*berseem.*
Third „ . . .	cotton	*berseem* or cereals.

Land ploughed after *berseem* and sown in maize gives a much finer seed bed for cotton than after *berseem* sown in rice land, with a proportionately better yield.

The *ezba* accommodation necessary for fully developed land is one room per four acres of let land, and it is preferable to build the *ezbas* in burnt brick.

Cost of Development of 3000 *Acres.*

Canalisation, £1 per acre	£3,000
Sluices, culverts, bridges, and pipes, £·5 per acre	1,500
Levelling by cattle and engines, £5 per acre	15,000
Ezba buildings—1 room per 4 acres—750 rooms with courtyards at £15 (no allowance for cattle sheds, as they are convertible into rooms)	11,250
Houses for staff, offices, and magazines	3,000
Drainage installation, £·8 per acre	2,400
Washing and loss on cultivation of reclamation crops, £5 per acre . .	15,000
Cost of pumping drainage, £·20 per acre for three years, £·60 per acre .	1,800
Cattle purchased:—60 pairs at £35 per pair, £2100; of which depreciation 20 per cent. chargeable to cost of development . . .	420
2 pairs of ploughing engines with tackle complete, £4500, of which 50 per cent depreciation chargeable to cost of development . .	2,250
Drain and canal clearances	1,500
Sakias, ploughs, and implements	580
Management, 12½ per cent. of capital expenditure	7,300
	£65,000

Say £22 per acre.

Land tax charged by Government during period of reclamation is sometimes also added to the capital cost of development. This may vary from £·02 to £·50 or more per acre per annum. No allowance is made in this calculation for interest on capital. I have put the cost of levelling fairly high, and this item of course varies very much on different properties and depends on the acreage of *Kardud* lands there is to level."

CHAPTER IX.

THE NILE IN FLOOD.

101. The Nile Banks.—102. Culverts in the Nile Banks.—103. Nile Spurs.—104. The Theory of River Protection and Training.—105. Training Works on the Nile.—106. River Training and Land Reclamation.—107. The Nile in Flood.—108. Nile Bank Protection.—109. Silt Deposits in Canals (General).—110. Silt Deposits in Canals in Egypt.

101. **The Nile Banks.**—The Nile, during flood, is considerably higher than the level of the country, which is protected by longitudinal embankments. In the southern parts of Upper Egypt a high flood rises about

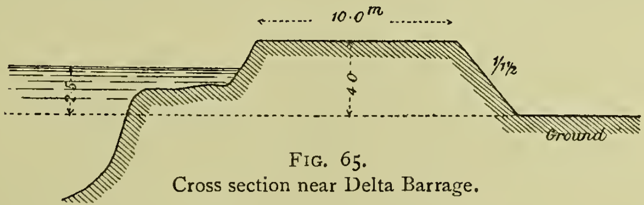


FIG. 65.
Cross section near Delta Barrage.

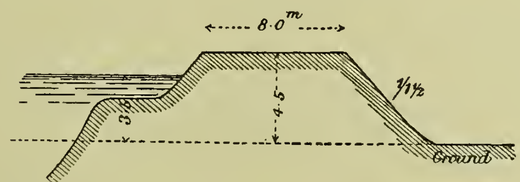


FIG. 66.—Cross section 100 kilometres from Delta Barrage.

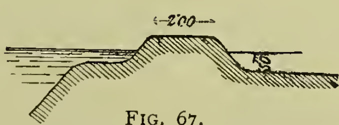


FIG. 67.
Cross section near the sea.

1 metre above the level of the country, and the longitudinal banks along the river, being comparatively insignificant, are frequently breached. These breaches are beneficial rather than otherwise, as they allow the high lands near the river's edge to be well washed. In Middle Egypt, where perennial irrigation has taken the place of basin irrigation, the banks are as important as those in Lower Egypt and follow the same rules. The

longitudinal sections of the Rosetta and Damietta branches of the river in Lower Egypt show the height of the floods above the level of the country to be in places as much as 3·5 metres. The cross sections of the banks are anything but uniform; they vary from a 10-metre top width near the bifurcation to 2 metres near the sea.

The preceding sections show the Nile banks as they actually were in 1897.

The following type sections of banks have been fixed by Major, now Sir Hanbury, Brown, and are at present being worked to:—

TYPE SECTIONS FOR NILE BANKS, LOWER EGYPT.

Showing the minimum dimensions that the banks should have under different conditions, to be adopted for all new portions of the Nile banks and whenever any lengths of banks require extensive repairs.

Scale $\frac{1}{100}$.

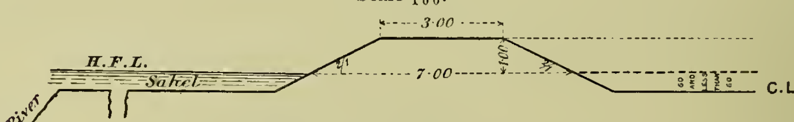


FIG. 68.—Minimum section, to be adopted when high flood level does not exceed 0·50 above country level inside banks.

If the soil is sandy, crest width to be increased to 4 metres.
If the bank is used as a road, the crest width to be 4 metres.

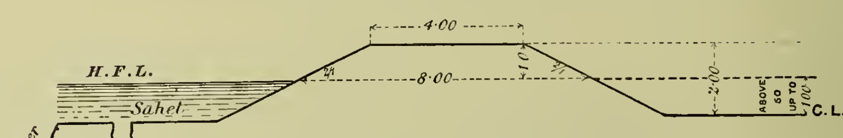


FIG. 69.—Section, when H.F.L. is over 0·50, but not more than 1·00 metre above C.L. inside bank.

If the bank is used as a road, the crest width to be 5·0 metres.

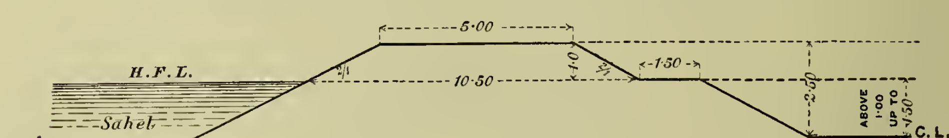


FIG. 70.—Section, when H.F.L. is over 1·00, but not more than 1·50 above C.L. inside bank.

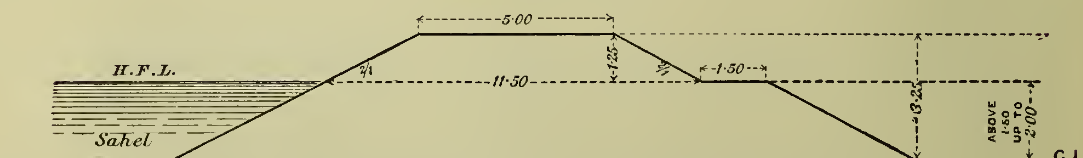


FIG. 71.—Section, when H.F.L. is over 1·50, but not more than 2·00 above C.L. inside bank.

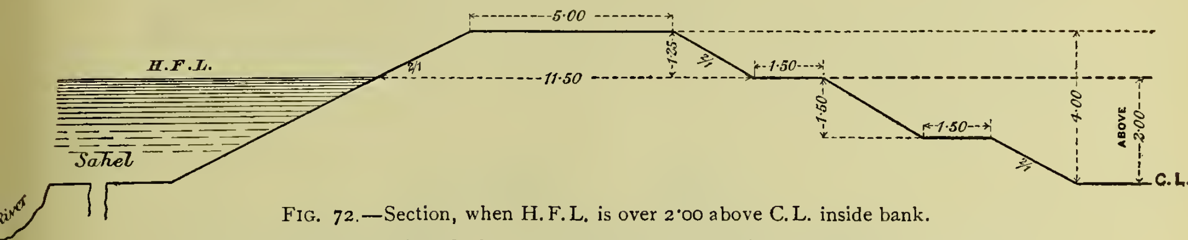


FIG. 72.—Section, when H.F.L. is over 2·00 above C.L. inside bank.

Note.—If the infiltration is bad, the lower slopes on the land side to be made $\frac{3}{1}$, or even flatter, as experience may show to be necessary.

If the soil is very sandy, the slopes should be $\frac{3}{1}$, in which case the land side offsets will be omitted.

(*N.B.*—"Sahel" means berm. C.L. = country level. H.F.L. = high flood level.)

The danger from high floods does not lie so much in the weakness of the banks as in the absence of berm along considerable lengths of the river, and in the presence of numerous culverts in the banks which are always a source of anxiety. With respect to the berm, we consider that every circle might with advantage devote a fixed sum annually to throwing back the bank about 40 metres from the edge of the Nile at all places where spurs are put up. The spurs would stop further encroachments of the river on the particular reaches where they were put up, while a 40-metre berm would ensure the bank between the spurs from being undermined at any stage of the flood. This undermining frequently takes place in winter and early summer, when the Nile is low and the winds strong, although the effects of it are first evident when the Nile comes down in flood. As long as whole kilometres of bank exist without any berm whatever, the country can never be considered as protected from the dangers of a breach in flood.

102. **Culverts in the Nile Banks.**—Culverts in the Nile banks are necessary for the summer irrigation of the fields near the Nile. Where

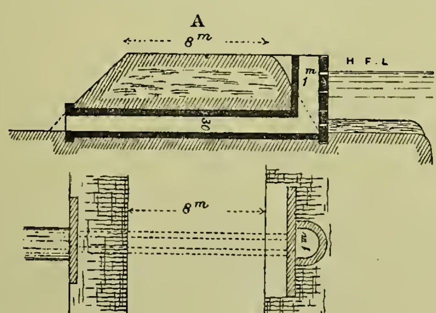


FIG. 73.

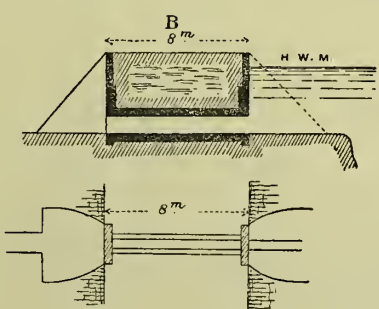
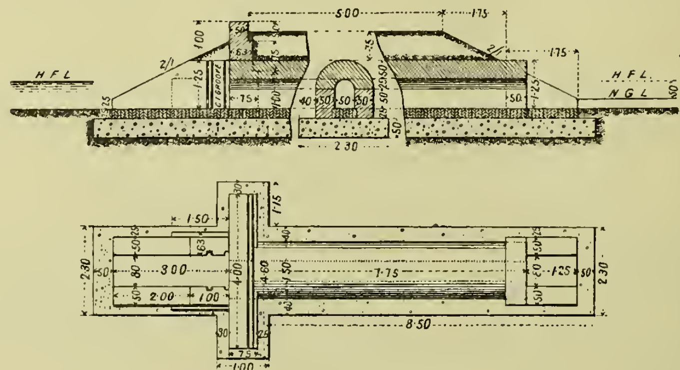


FIG. 74.

they were constructed of good masonry, of sufficient length, and with a well in front, they were not dangerous; but as a rule they were badly built, and not nearly long enough. The preceding cross sections (figs. 73 and 74) give (A) a good culvert, and (B) a dangerous one as they formerly existed.

Recently type drawings for Nile culverts were issued by Mr W. R. Williams, Inspector-General of Land Irrigation, Lower Egypt, and are here given in full:—

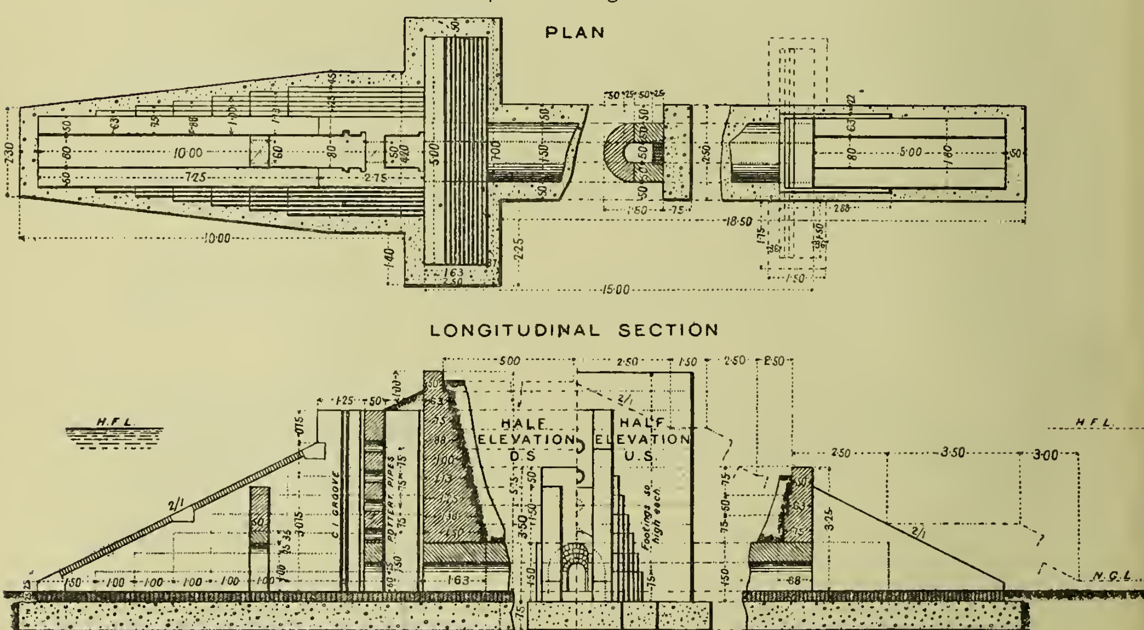
Flood ·50 above ground-level.



Approximate Cost £65.

Fig. 75.

Flood 4·0 m. above ground-level.



Approximate Cost £365.

Fig. 76.

103. **Nile Spurs.**—Where there is a considerable berm, or where the velocity of the stream is inconsiderable, no protective or training

works are immediately necessary, and none are undertaken. Where, however, the action along the Nile bank is severe, the banks as a rule are protected either by having stone spread over the slope, or by stone spurs. Where the soil is good, protective works of any kind are effective; where, however, strata of sand are met with, a good deal of skill is necessary to make the protective works effective. The spreading of stone over the slopes is very costly, and needs frequent renewals owing to slips; it is, as a rule, adopted only in front of villages and towns, where property is

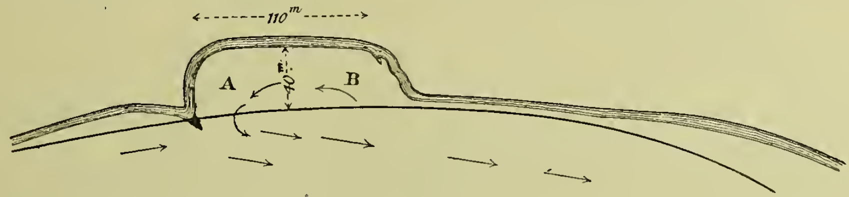


FIG. 77.

valuable and it is desirable to preserve the bank in its existing state. At all other places stone spurs are put up. These spurs cause severe action just below themselves, but thoroughly protect the bank. If there is no berm, or the berm is less than 40 metres in width, care should be taken, before putting in the spurs, to throw back the bank. We consider the best alignment to give the new bank is to throw it back as in the preceding figure. Be the action of the spur never so severe, the water will weary itself in a space 110 × 40 metres in area. By the action of the spurs the thread of the current is thrown away from the bank. Since protection of a bank by this system of spurs concentrates the current, and makes its action more severe, it is very unadvisable to put in the upstream spurs D,

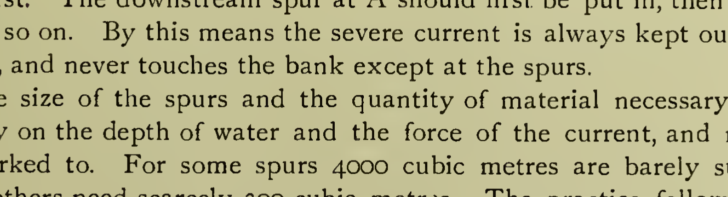


FIG. 78.

C, B first. The downstream spur at A should first be put in, then B, then C, and so on. By this means the severe current is always kept out in the stream, and never touches the bank except at the spurs.

The size of the spurs and the quantity of material necessary depend entirely on the depth of water and the force of the current, and no rules are worked to. For some spurs 4000 cubic metres are barely sufficient, while others need scarcely 300 cubic metres. The practice followed is to make the spurs at first as small as possible, and then add to them every year. The Nile in passing round the curves has very often a considerable

spill channel at A; the larger this channel the less severe is the action at B. Where there are no spill channels, protective works are doubly

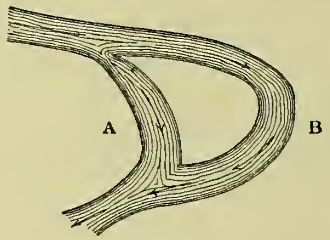


Fig. 79.

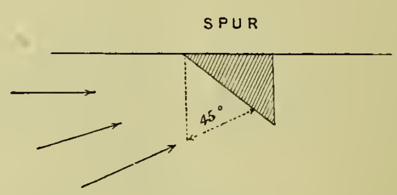


Fig. 80.

necessary. The following rules have generally guided the irrigation officers in the construction of spurs:—

1. No spur is to be put in at a right angle to the current, but always at an angle of 135°. As the river rises in flood, the current changes considerably, and if the spur were put at right angles to the cold-weather current, it might even meet the flood at an acute angle.

2. The top of the spur is to be on a gentle incline as at A, and not abrupt as at B. A spur like B produces very severe action just below itself, without any compensating advantage.

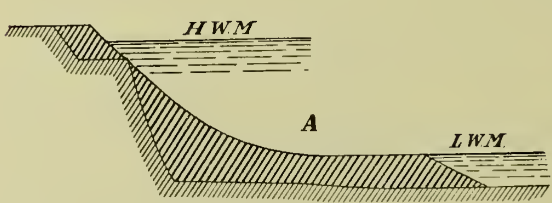


Fig. 81.

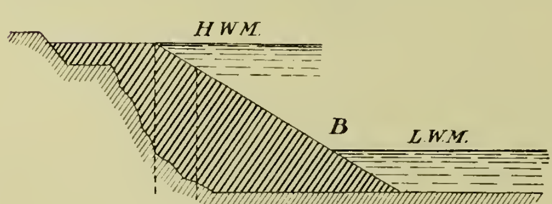


Fig. 82.

A spur at an angle of 135° and on an incline gives a maximum of efficiency not only for a minimum of money, but also with the least action, and consequently with the least danger.

3. The spur is always to be tied well back to the bank, and if there is a berm, the spur is to be continued on the berm right up to the Nile bank.

Spurs such as those at A might be taken out well into the current. A few powerful spurs like these are far more effective and more economical than a large number of small spurs which only irritate the Nile and do little else. Between two spurs well placed and boldly handled there is always a foreshore of sand which completely protects the banks from the wearing action of the waves driven by the strong north-west winds during the low stages of the river.

The following rules and examples of spurs were laid down by Mr G.

B. Ireland, in 1910, when acting Inspector-General of Irrigation; but we consider a spur of our type A as just given, as more effective. Mr Ireland contends that his are better for navigation.

Rules for Construction of River Spurs.

Crest 2 metres wide.

Side slopes 1/1.

End slopes 1/1, carried 1 metre above L.W.L. or to W.L. when spur is being formed.

Superior slope to vary from 1 in 2 to 1 in 10 to suit conditions and length of spur.

Axis of spur to be inclined at 60° to direction of current.

A B line drawn through root of spur parallel to direction of current.

Land end of superior slope to be half a metre above H.F.L., and one metre at least within river edge.

All spurs to be connected with the Nile bank behind them by a bank of earth, called the "tie-back": crest 3 metres wide, side slopes 2/1, aligned at right angles to the bank to which the spur is tied, that is, along the shortest line: the slope exposed to wind action to be revetted to half a metre above H.F.L.

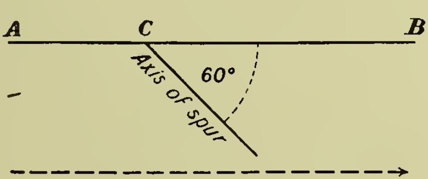


FIG. 83.

From the above rules it will result that the longer the spur the flatter the superior slope will be for the same differences of level between H.F.L. and L.W.L.: and for equal lengths of spur the less the difference between H.F.L. and L.W.L., the flatter the superior slope will be.

104. **The Theory of River Protection and Training.**—Some of the laws of transport of silt are still the object of investigation, and are therefore not definite, but on the whole the following statements are correct.

The power of transport or suspension depends on the rate of change of velocity from one filament of the current to the next, and not directly on the velocity. In turbulent rivers, *i.e.* those where the water is moving with considerable eddying motion, the rate of change is sometimes very great. Hence in such rivers, as is well known, the power of transport is considerable. Turbulence depends on the forward velocity of the water, but also on several other factors. It is increased rapidly by increase of temperature, by increase of the depth of the river relative to the breadth, and by obstacles of any description to the even flow of the water. Thus it is greatest behind the piers of bridges or after the flow past regulators, and is augmented by obstructions such as snags or spurs projecting into the river. This is very evident in most of the spurs.

The transportability of the material depends on the sixth power of the radius. Thus fine silt is very easily transported, coarse sand less so.

The power of transport or suspension (which involves transport) is limited, *i.e.* each filament can carry a certain amount and not more than that amount of silt. When it is carrying its maximum amount, it is said to be saturated ; and if any more is then added, there must be a precipitation to reduce the amount to saturation point. If, on the other hand, the water is not saturated, it will, if it gets the chance, take up more silt. Hence when the turbulence of a canal is increased just below a regulator, the water takes up the silt which it is able to excavate and carries it on till, by internal friction, the turbulence is diminished and the now supersaturated water deposits its silt.

The laws of scour are not quite the same as the laws of transport, but are analogous. Here the scour depends on the pressure which the water is able to effect on the particles, on the size and weight of the particles, on the surface exposed to the water's action, and on the tenacity with which one particle clings to the next. Smoothness or roundness in the particles will diminish the pressure, but will decrease the tenacity. A mixture of various sizes of silt will probably diminish the surface on which the water can bear, and will decrease scour. Finally, scour will in all probability be increased if the particles are acted on from a different direction from that in which they were acted on when laid down by the water. Thus particles attacked by a current acting upstream are more likely to be readily detached than when acted on downstream.

We now come to the general law of the flow of water. Water, of course, obeys the laws of motion. This is true of the particles, and we may extend the laws to considerable volumes of the liquid. Thus a mass of water flowing downstream will move in a straight line unless acted on by some lateral force. Hence when such a mass comes to a bend on the river it keeps straight on, until by its accumulation against the bank in front, a head is created which drives it round the bend. The lateral force will vary as the square of the velocity, and inversely as the radius of the bend. In the end, of course, the lateral force is provided by the pressure of the bank. Hence at a bend the bank, and its ultimate particles, have to oppose not only the frictional force of the water that would be met in a straight reach, but also the "centrifugal force" of the water.

Scour is therefore heaviest at bends, and as the movement of the water becomes more complex there, turbulence is favoured, and the scoured material is more readily transported.

It will generally be found that the straight forward movement of the water across to one side of a bend implies a portion of slack water opposite. Thus the river moving as shown in the diagram tends to strike the bank between A and B and to leave slack water at C. Here in general

some of the water becomes supersaturated and deposits its silt, but this might not be the case if for some reason or other there was an increase of turbulence at C.

The bank at A and B may be protected by cemented or loose pitching, provided the stones are of such a size that it becomes impossible for the water-pressure to set up force enough to move them and the pitching has its toe on solid soil or an artificially prepared solid base on sand. Such a base can be secured by strong verticals driven deep into the sandy bed, and tied at low water by strong horizontal pieces. This is theoretically the best means of protection. Its practical limit is, of course, its cost, but it may be made permanently effective, subject to repairs where imperfection of the work causes damage.

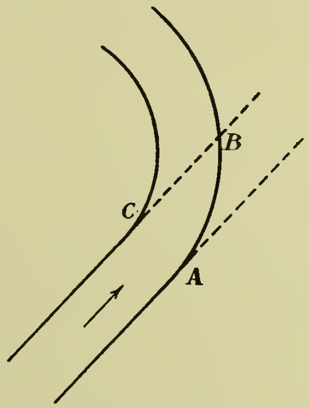


FIG. 84.

Protection by spurs is theoretically not so sound. Suppose a spur is placed between A and B in fig. 84. Its effect is seen in fig. 85. The effect of the spur is to deflect a portion of the current, as at D. This portion is chiefly at the surface, as the slanting side of the spur upstream face tends to throw the current to the surface But the amount of the current so deflected is very small compared with the great volume of the current which sweeps on without deflexion, and strikes the bank somewhere in the neighbourhood of E. As the deflected current at D is raised to the surface, the undeflected portion may sweep on hidden by this upper current. From the present point of view, however, the bank is partially protected by the spur at D, which undoubtedly takes up some of the shock of the water. But there is another point to be taken into consideration. The viscosity of the water causes the rapidly moving water at D to set up eddies in the dead water behind the spur. These eddies are strongest just along the line of discontinuity between the rapid current and the dead water, and though each is at first small, the diameter goes on increasing and the rotation becoming greater, until the eddy becomes in some way unstable, breaks away from the line of discontinuity, and moves off

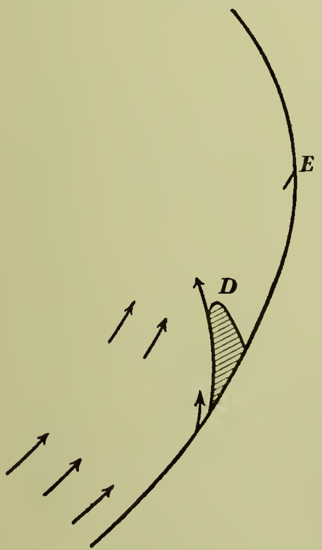


FIG. 85.

into the dead water. The result is the creation of a sort of whirl behind the spur. This may be aggravated by the action of the sub-current that is flowing direct to E, with a consequent upward flow. In any case we get a whirl where the water is moving upstream along the bank from E to D, and with considerable turbulence. Turbulence is always associated with rapid changes of velocity. Hence from D to E the particles of the bank are subject to rapid changes of the shock of water. The grains are thus more easily loosened than they might be if subjected to steady impulse in one direction, just as a picket which successfully resists the steady pull of a cable is easily disturbed by successive small blows on alternate sides.

The result of this whirl is nearly always that a cavity is formed behind the spur. Whether the spur is effective or not depends on the respective magnitudes of the protective action and this excavating action. In general, however, it is probable that the excavating action will gain the upper hand in the long run, because the spur does not remove the actual cause of the scour, but deals with only part of it.

The radical removal of scour can be effected by removing the main cause of the scour, the crookedness or excessive crookedness of the channel. This necessitates the gradual creation of a new and straighter channel. There is no essential difficulty in this: all depends on the cost, and whether the money is available. It is, however, sound engineering to continue spending annual sums in maintaining an imperfect system made better annually, as each well-placed spur is constructed, rather than to effect a radical cure by incurring a ruinously heavy capital expenditure. Before leaving the subject, however, it may be well to mention one disadvantage and one great advantage. The disadvantage is that by creating a straighter channel, the slope would be increased, and thereby velocities would be increased. The chief effect of this would be a slight deepening of the channel. The advantage is that as velocities were increased, gauge-readings for a given discharge would be reduced. Thus the tendency to breaching would be decreased, and the fear of flood damage lessened.

If, however, it is accepted that the radical cure cannot be undertaken, and the present system must be continued, it remains to see how to get the most out of this system. The question is so complicated that it is almost impossible to look for a solution on *a priori* or theoretical principles. We are left therefore to trial and error. In practice this is expensive. But it is possible by using models to work inexpensively and obtain experience capable of being utilised effectively in practice. Models for hydraulic purposes have been used now for forty years in shipbuilding with the most excellent results. They have been used in studying the behaviour of the tides in estuaries both in Great Britain and in France, and again the results have been most satisfactory. They have been used in Germany

actually to study the effect of projected changes on river channels, and there are several hydraulic laboratories for studying such engineering problems now in operation in that country. It is not therefore an untried scheme that we are recommending, but one which has succeeded well elsewhere. The laws connecting the vertical and horizontal scales, the slopes, the velocities, the coarseness of the sand to be used, etc., are all well known, and the effects obtained in the model can be translated into terms of actual practice.*

We estimate that for this work, models on a scale of from $\frac{1}{500}$ to $\frac{1}{1000}$ horizontally would be best, and the cost in plaster of Paris would be about £10 per model. There would be some initial cost for the pumping plant, but this would be small. Reynolds' paper on certain laws relating to the régime of rivers is well worth consulting. It will be found in the *British Association Report* for 1887, or in his *Collected Papers*, vol. ii. p. 326.

Some very interesting problems on river training were met with on the Tigris, and we quote from *Irrigation in Mesopotamia* :—

"From the above it will be seen that there are four branches of the Tigris which endanger the navigation of the river by withdrawing large quantities of water from the parent stream. The first is the Bitera, above Amara. Here the danger may be taken as not very serious, as the discharge in low supply is insignificant. But the three remaining branches, the Chala, the Majar Kabir, and the Machera, are a serious menace to the existence of the river; and works for the proper regulation of all of them should be taken in hand if any serious effort is to be made to keep communication open between Bagdad and Basra.

The principles which underlie the designing of works such as these are well known by hydraulic engineers, and these works have been designed in accordance with them. Three main points are essential: firstly, to allow that portion of the high flood to escape freely which the river itself could in no wise carry; secondly, to prevent the water at low supply from so escaping that the main river itself run dry; and thirdly, to provide a fixed crest so that no regulation be required. The first of these three essentials, viz., the necessary waterway in flood, might be formed by building the barrage at an angle to the current of the stream, but it has been thought preferable to obtain it by lengthening the barrage and building at right angles. The second point is gained by keeping the level of the crest of the weir a little below extreme low water. The crest has been designed always at 50 centimetres below low water. The third point is gained by designing the barrage as a solid weir. The works may, therefore, be described as solid, substantial waste weirs with crests 50 centimetres below low-water level and lengths such that the areas between the crests and high-flood level are exactly those of the branches themselves in high flood to-day."

105. Training Works on the Nile.—We quote from the second edition :—

"Few attempts have been made at river training in Egypt, but where they have been made they have been very successful. The training works have been ruled

* See Osborne Reynolds, *Collected Papers*, vol. ii. p. 393.

by the following principles: (1) That all training works should be put in the shallow water at the tail of the last shoal above the point operated on; thus, in the accompanying sketch, where the river is wanted to leave the channel A C B and adopt the channel A D B, the first year's spurs are put in at M and N, the next year's at O and P, the third year's at Q and R, and so on. (2) A permeable

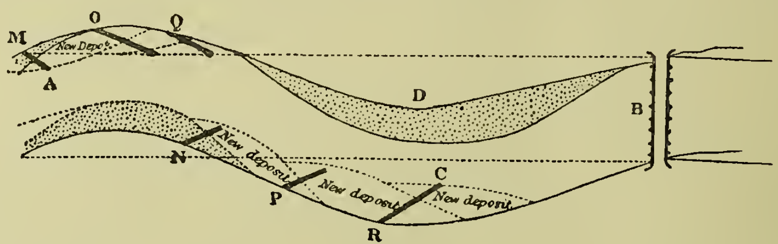


Fig. 86.

spur is better than a solid one. Acacia trees anchored in a line were employed. Each tree had an anchor of its own, and was independent of the others. Large trees cost about £3 in position, and the chain and half-ton anchor costs about £3 more.

The Nile just above the Rosetta branch Barrage was trained very effectively by Colonel Western in 1887, 1888, 1889, and 1890 in this way; as was also the Rosetta branch near Shabshir Tamallay near the spot where the terrible breach of 1863 occurred. M. Mougel, who designed and built the Delta Barrage, trained the

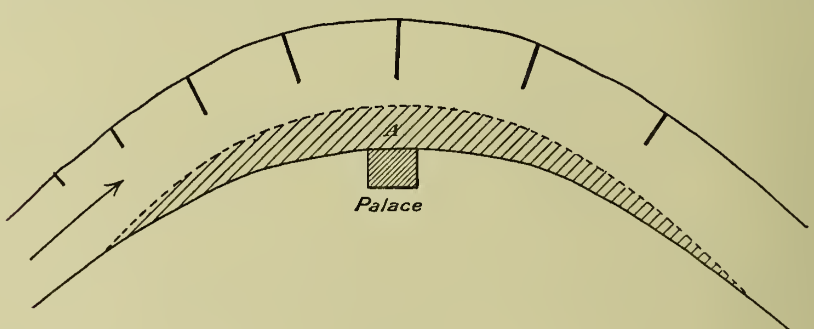


Fig. 87.

Damietta branch north of Benha by a series of long low spurs, as in fig. 87, and created deep water in front of Abbas the First's palace there.

The place occupied originally by the sandshore A now became the deep channel of the river. This is exactly what Rameses the Great's engineers did at the Temple of Jerf Hussein in Nubia.

Among other methods of training, that employed by Mr Eads on the Mississippi with marked success (the Mississippi has three times the flood discharge of the Nile) might be adopted with advantage in Egypt. The following is a résumé of Mr Eads' argument. Though much has been written on the subject since his day, no one has seen more clearly or applied their theories more effectively than that singularly bold and original engineer.

'His plan of jetties or permeable spurs was based upon a knowledge of the fact

that the Mississippi River is a transporter of solid material, almost all of which is held in suspension by the mechanical effect of the current; and that the quantity of matter which it is able to carry increases with the square of the velocity. The current of the river is caused by the fall of the water from a higher to a lower level, that is, by the force of gravity. The element which resists the current is the friction of its bed. This friction does not follow the law of solids, but increases or diminishes exactly as the width of bed or wetted perimeter of its cross section is increased or diminished. Hence, if the stream is contracted, where it is too wide, to one-half its width, one-half of the frictional resistance will be gone, and the current will be more rapid, and therefore more able to carry a larger load of sediment. He then states, " By some, caving banks are attributed to the direct action of the current against them, by which strata of sand underlying those of clay are supposed to be washed out. This is not correct. If the water be charged with sediment to its normal carrying capacity, it cannot take up more unless the rate of current be increased. Caving banks are caused wholly by the alterations in the velocity of the current. Alterations are inseparable from a curved channel, because the current in the head is usually more rapid than on the point, but if the channel

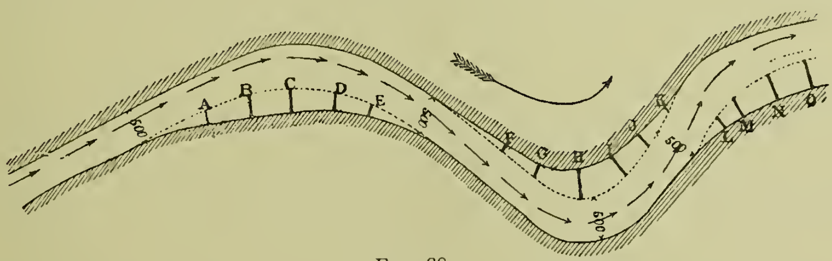


FIG. 88.

be nearly uniform in width, the caving caused by the curves will be very trifling; and in proof of this, many abrupt curves exist in the lower part of the river, where the whole force of the current has set for years directly against them without any important caving of the banks. The curve at Fort St Philip is a notable instance, the great difference in the width of the flood-channel constituting the real cause of the destruction and caving of the banks. This tends to great irregularities in the slope of the flood-line, and consequently great changes in current velocity, by which a scouring and depositing action are alternately brought into very active operation. The whole of the river below Red River proves this. Caving banks are much less frequent there than above, because the flood-width of the river is far more uniform. A correction of the *high-water channel*, by reducing it to an approximate uniformity of width, would give uniformity to its slope and current, almost entirely preventing the caving of its banks. By such works the flood can be permanently lowered." The jetties or spurs were made of piles and willows, and were permeable to the flood.'

To treat the Nile on this principle it would be necessary to fix first upon the uniform top width to be adopted. Say 500 metres for the Rosetta branch. By referring to the sketch, it will be seen that the river could be brought to a uniform top width by building light, inexpensive spurs on the sandy shoals. The land between these spurs would rise rapidly and become cultivable. This system of training might have the great advantage of paying its way.

There are many places where the reclamation of the sandy shoals would almost pay for the construction of the spurs. This would be in addition to the training of the river."

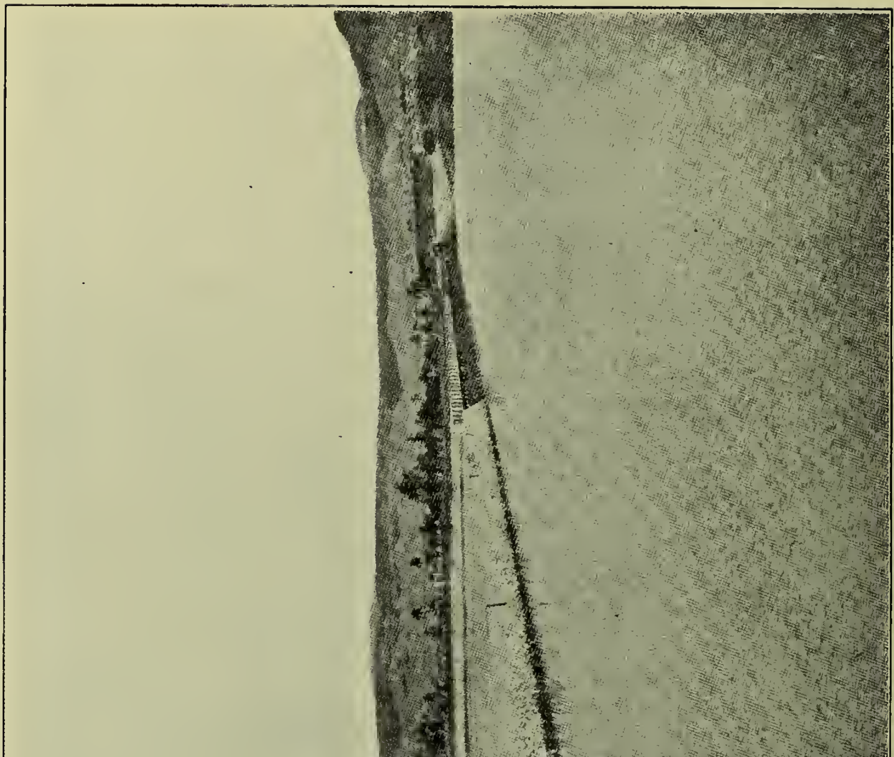
106. **River Training and Land Reclamation.**—We have just quoted from the second edition the statement that "the reclamation of the sandy shoals would almost pay for the construction of the spurs." With this idea one of us proposed the construction of certain training works in the river to the New Egyptian Company in 1899, and recommended tentative works. The Company then engaged Mr J. S. Beresford, C.S.I., in the forefront of Indian engineers, who lifted this work into an art. The first work was a solid stone overflow weir across a narrow branch of the Nile near Sohag. The experience gained here showed that solid overflow weirs were of little value. Recourse was then had to inexpensive but at the same time very effective regulators with needles across arms of the river. These have given very good results and are quite a feature on the Nile. They consist generally of barrages with 3-metre openings and 1-metre wide piers, closed by wooden needles about 10 centimetres square, spaced so as to give roughly the width of the needle as openings. Many of these needles are fixed to the horizontals, and some are movable. In the photograph of the Ashment Khôr, the left flank has movable needles, while those on the right flank are fixed. The general height may be taken as 5 to 5·50 metres. The works are well designed and look very well. The following quotation and photographs are from the Irrigation Report for 1905 :—

"*Nile Land Reclamation Works.*—The following note, kindly supplied by Mr J. S. Beresford, C.S.I., Consulting Engineer of the New Egyptian Company, describes the works carried out during the year under review :—

'Surveys and all arrangements were made by the Company for undertaking three new sites in 1905, namely, at Ashment, Luxor, and Bayadia; but owing to the Government having at the last moment unexpectedly refused formally to sanction commencing work on the two latter sites, operations were confined to the Ashment site, where a regulator of formidable dimensions was successfully constructed under great difficulties. Two deep branches of the river, feeding the Khor, and carrying over half the discharge of the Nile, with a rapid current, had to be closed as a preliminary measure, necessitating the use of novel engineering expedients, one of these being the laying of a carpet of strong sail-cloth, 270 metres long by 20 metres wide, on the sandy bed to protect the latter from erosion during the operation of closing the channels. This regulator, which is the largest of the kind on the river, worked satisfactorily during the flood, leading to the formation of a considerable area of new land, and at the same time effecting an improvement in the navigable channel of the river. Sir William Garstin had an opportunity of seeing the regulator at Ashment on his way down the river, early in February of 1906, and was able to judge for himself the size and importance of this work.

The works carried out by the Company in previous years were maintained in good order, and all of them worked satisfactorily during the flood of 1905, considering its unfavourable nature.'

Ashment West Regulator (Downstream).



Feshn Regulator from Upstream in Flood).

Mr Beresford also forwards some views of the Company's regulators at Ashment and Feshn." See Plates XXXVI. and XXXVII.

107. **The Nile in Flood.**—The following is taken verbatim from the second edition :—

"The Nile is in flood annually during the months of August, September, October, and November. The maximum rise at Aswan is 9·10 metres, and at Cairo 8·70. The mean rise is 8 metres at the former and 7 metres at the latter.

Up to a gauge of 7 metres at Cairo there is no danger: beyond that there may be danger, and harm is done both by infiltration and direct swamping of standing crops on the berms. The ordinary duration of a flood above this level is fifteen days, the maximum duration has been three months.

The two highest floods in this century of which there is any record were in 1874 and 1878. The flood of 1878 was slightly in excess at Aswan. The flood of 1874 was at its highest at Aswan about the 5th of September, when the basins were being filled in Upper Egypt, and irrigation in Lower Egypt brisk everywhere. The river had fallen considerably by the 1st of October when the basins were opened, and consequently it was possible to get through without serious breaches in Lower Egypt, in spite of the Nile banks at the time being in an indifferent condition. The flood of 1878 was very different. The gauge at Aswan was at its highest on the 1st of October when the basins began to be opened or opened themselves, and irrigation in Lower Egypt was slack. The opening of the basins was the signal for an inundation such as Egypt can seldom have seen. The Cairo and Barrage gauges of October, though high, were not nearly so high as they would have been had not the left bank of the Nile breached, south of Cairo, and a considerable portion of the flood water escaped through the province of Giza into the Rosetta Nile, sweeping away the railway bridge near Menashi.

The Rosetta branch rose at Kafr el Zayat 1 metre higher than the level corresponding to the Barrage gauge of the time; but owing to the great capacity of this branch of the Nile, it was able to carry the supply without flooding the whole country. The height of the flood was so extraordinary that the railway authorities marked the maximum rise against the right abutment of the Kafr el Zayat bridge, and cut the figures 1878 against it.

The Damietta Nile did not fare so well. The flood came on at a time when all the canal-heads which take out of this branch had been partially closed, and water was not in much demand. The branch itself, after passing Zifta, has a very contracted channel, and could not carry the supply. The flood rose to nearly the full height of the banks, and eventually breached the left bank of the river, midway between Zifta and Samanûd, and destroyed the standing crops and every village that lay between it and the sea. If the Damietta branch had not been relieved by the breach near Cairo, which discharged into the Rosetta branch, the damage would have been incalculable. As explained previously, the Upper Egypt basins must begin to be opened early in October, or they will not dry in time to allow the winter crop to be sown in season.

Before the construction of the Barrages, the maximum discharges of the Rosetta and Damietta branches of the Nile in flood were nearly the same at the head of the Delta proper.* A little lower down, however, the Rosetta branch had considerably

* *Vide* the notes on Linant Pasha's hydrographic map of Lower Egypt.

more water than the Damietta. About 2 kilometres below the Barrages there was a branch called the Shalakân branch, which flowed from the Damietta into the Rosetta Nile. About 20 kilometres below the Barrage the Bahr Ferunia took about one-third the total quantity of water out of the Damietta branch and threw it into the Rosetta branch. Both these were closed by Mohamed Ali; and at the same time the Bahrs Sirsâwia, Baguría, Shebîn, Kadrawîa, Moês, Um Salâma, Mansuria, and Saghêr, were also completely closed, or provided with regulating heads, which very considerably diminished their discharge. Previously they had discharged a very considerable quantity of water, which left the Damietta branch a comparatively insignificant stream. The cross sections of the Damietta branch near the Barrages and at different points down its course have considerably contracted. The cross sections of the Rosetta branch, on the other hand, maintain a fairly uniform section along its entire length.

The closing of the Bahrs Shalakân and Ferunia has caused the Damietta branch in its upper reaches near the Barrage to suit its section to the contracted section lower down. This it has done by silting up its bed and becoming a broad, shallow stream, which in a very high flood has at its head a considerable increase of discharge for a slight rise of the gauge. This excess discharge in high flood causes great anxiety lower down where the section is contracted. The Karanain regulator at the head of the old Bahr Shebîn, taking from the Damietta branch below the Bahr Ferunia, was built in 1842 by Linant Pasha, with its wing wall 60 centimetres higher than any previous flood. By 1870 the Nile had risen 70 centimetres above the wing wall, as measured by Linant Pasha, though Aswan had shown no signs of increase. In 1878, though the Damietta branch was relieved by the Giza breach, which discharged into the Rosetta branch, the flood-water surface was 1·50 metres above the wing wall.

From the above considerations it will be evident that the Damietta branch should be trained near its head by long spurs on one bank, so as to contract its channel to half its present size in width, and deepen its bed. This will allow more water to go down in winter and summer, when it is needed, and less in high flood, when it is dangerous. To make the Damietta branch Barrage capable of holding up water in high flood is very desirable. It would ensure the Damietta branch from breaches. But at the same time the Rosetta branch Barrage should have its waterway increased from sixty-one openings to eighty openings. The alternative project is the construction of powerful regulators in the basin banks right through the Giza Province from Koshêsha to the Rosetta branch. This latter arrangement would permit of the Middle Egypt basin water in a very high flood finding its way direct to the Rosetta branch without endangering either Cairo or the Damietta branch. In case of extreme necessity, it would even be possible to relieve the Nile through the Koshêsha escape, using it in the reverse way to what it is used ordinarily. This latter project, if thoroughly carried out, would confer very great benefits on the Giza basins and minimise the dangers of a very high flood in Lower Egypt.

Besides regulation at the Damietta Barrage, there are two other methods available for reducing supply in this branch during a high flood. One of these is the construction of a second mouth to the Damietta branch from near Ras el Khalîg to the mouth of the Bahr Shebîn. It would be necessary to make two good banks in the small patch of cultivated land near the Nile, about 500 metres apart, and let

the Nile sweep over the Berea, reclaiming land along its entire length. The other is the construction of a reservoir in the Wadi Rayan, which will be considered in Chapter XII.

The Nile flood of 1887 was the highest which the country has experienced since 1878, and an account of it will not be without interest. It has been impossible to get any full accounts of former floods.

As far as can be learned, the flood never before attained the level of R.L. 20·25 metres at Cairo without there being disastrous inundations.

In 1861 (the Cairo gauge being R.L. 20·43 metres) the right bank of the Damietta branch was breached at Sumbakht, north of Mit Ghamr.

In 1863 (the Cairo gauge being R.L. 20·61 metres) the left bank was breached at Talka, opposite Mansura, and the same year the right bank of the Rosetta branch was breached at Nadir in Menufia, opposite Khatatba.

In 1866 (the Cairo gauge being R.L. 20·90 metres) the right bank of the Damietta branch was breached at Sefer and Mit Damsis, north of Mit Ghamr; the right bank of the Rosetta branch near Dessuk.

In 1869 (the Cairo gauge being R.L. 20·92 metres) the left bank of the Damietta branch was breached at Kafr el Hataba, north of Mansura.

In 1874 (the Cairo gauge being R.L. 21·40 metres) the right bank of the Damietta branch was breached at the head of the Bahr Moês, the left bank at Batra, north of Mansura; the Rosetta branch was breached on its right bank at Dessuk, and again at Gezira el Fars 10 miles south of Rosetta. In the 10 kilometres south of Rosetta, this branch of the Nile on its right bank is exceedingly dangerous.

In 1878 (the Cairo gauge being R.L. 21·27 metres) the Nile was breached at the head of the Sharkawia Canal north of Shubra; the Damietta branch on its right bank at the Bahr Moês head and at Sharabas north of Faraskur; and on its left bank at Mit Badr Halawa between Zifta and Samanûd. The Rosetta branch was breached again at Dessuk, and on the left bank in many places between Khatatba and Kafr Zayat, but these latter breaches were insignificant.

The great breach of Mit Badr Halawa has left a marked impression in Egypt. Serious loss of life then occurred. But even more serious was the Nadir breach in September 1863, which occurred early in the flood and could not be closed until the waters subsided; the water moreover travelled down the valley of the Bagûr, where the canals had no high banks to which the people could run for refuge, and where even a greater loss of life occurred than at Mit Badr.

In 1887 the flood rose to R.L. 20·65 metres on the Cairo gauge, and no breach occurred throughout Lower Egypt. The result of this was that the flood, having found no vent for escape beyond its banks, assumed graver proportions as it advanced. At the Barrage it was only 26 centimetres below the previous maximum. At Mansura it was 8 centimetres below the previous maximum. North of Shirbin it was the highest flood on record. Nearly everywhere throughout Lower Egypt it was the right or eastern bank of the river on which there was the heaviest action.

The first high flood after the disastrous one of 1878 was in 1887. The flood of 1887 has been fully described by Sir Colin Scott-Moncrieff in the Report for that year, and from it the following selection is taken:—

'The effects of excessive floods on Upper and Lower Egypt are widely different. In Lower Egypt it is necessary to irrigate all lands but to flood none.

In Upper Egypt vastly the larger proportion of the land is contained in great basins made on purpose to relieve the flood water, and so long as the embankments which divide these basins are not topped or carried away, the deeper the water the more the alluvial mud deposited, and the better the winter crops. While there are exceptionally high parts which in an ordinary year are not flooded at all, and remain uncultivated, but in a year like 1887 are as productive as the rest, the injury done in such a year is often more to the villages situated in the basins than to the crops. Every year these villages become islands in shallow lakes, but when the lake deepens discomfort must follow to the islands. The lower houses are swamped, the inhabitants are partially imprisoned, and the cattle suffer.

The great basins hardly ever spread to the Nile bank itself. The Nile berm bordering on the river is often too high to be covered by ordinary floods, and generally it is devoted to flood millets. This is either sown when the river is low, and laboriously watered by shadufs (or in August with the rising flood). The crop ripens during High Nile, and must be protected from inundation. This berm, which left to itself would be the richest in the country, has in many places deteriorated from the effects of over-cropping, and the efforts made to protect it against floodings have also protected it from the wholesome washing and renewal of the muddy Nile flood, so that salt efflorescence has taken place. The principal loss in Upper Egypt was the destruction of the flood millets; but, as Major Ross remarks, in many cases the proprietors looked on the loss with composure, knowing the benefit that their lands would derive from the fresh mud deposit. Moreover, they have seen that many who have protected their crops at great expense now regret having done so, as the filtrations through the loose soil bank of the berm practically destroyed the millets, and so lowered its yield that it did not pay; and now these men find their lands much salter than before.

Writing of the two southern provinces, Kena and Esna, Major Ross, Inspector-General of Irrigation, states that the rise of the Nile over that of 1886 was from ·76 to 1 metre; not a very great difference, but enough to inundate the whole of the berms for a period of thirty-six days (from 17th August to 23rd September). The water surface stood from ·40 to ·60 metre above ordinary full supply in the basins. Its slope was uniformly about ·07 metre per kilometre. The depth of water in the basins was from ·70 to 1·20 metre above what is considered full supply; the result of which was that the water of one basin stood back in that to the south of it, and the cross embankments were washed over by the waves and greatly injured. The longitudinal embankments parallel to the river suffered greatly too, and in many places the Nile overflowed them in a shallow film of water. The basin system failed then, and as far as the irrigation of the season was concerned no harm resulted (except to the millet crops), and much good.'

In Lower Egypt the whole country is under crop at the time of the flood, and has to be protected. A breach anywhere would be disastrous, while one in the first 100 kilometres might destroy the crops on 300,000 acres. From the first edition, which was written immediately after the high flood of 1887, is transcribed exactly what was then stated. The terror reigning over the whole country during a very high flood like that of 1887 is very striking to any one seeing a flood for the first time. On the settlement of a culvert in the Nile bank near Mit el Kholi, and the consequent first rush of water through the bank, one witnessed a scene which must have been common in Egypt on the occurrence of a serious breach, but which

fortunately was rare in 1887. The news that the Nile bank had breached spread fast through the village. The villagers rushed out on to the banks with their children, their cattle, and everything they possessed. The confusion was indescribable. A very narrow bank covered with children, buffaloes, poultry, and household furniture. The women assembled round the local saint's tomb, beating their breasts, kissing the tomb, and uttering loud shrieks. And every five minutes a gang of men running into the crowd, and carrying off something wherewith to close the breach. The fellahin, meanwhile, were not in the least confused, but in a steady, business-like manner were working at the breach, and closed it in half an hour. While the fellahin are left to themselves they have a very good idea of what should be done, but when one of the many hundreds of the civil employés on the Nile banks in flood is present, his ignorance and fear seem to take possession of the crowd. These employés are not engineers, and have not the least knowledge of any engineering fact in this world.

One often hears it stated that the best results are obtained from Egyptian subordinates if they are terrorised. I have always, however, found that terrorised subordinates are held back from work by their very fears. During the flood of 1887 I complimented an official on the Nile bank, whose activity was quite disproportionate to his apparent age. He told me that he was a comparatively young man, but that he had had charge of the Nile bank at Mit Badr Halawa when the great breach occurred in 1878, and that Ismail Pasha had telegraphed orders to throw him into the breach. He was given twelve hours' grace, and during the interval his hair had become white: subsequently he was pardoned. The memory of this senseless order had survived and sunk into the minds of other officials. As it happened, during the flood of 1887, a breach very nearly occurred on the right bank of the river. Arriving at the spot, Mr Langley, the Assistant Inspector, began working hard with a gang of men fighting the flood. He saw the district engineer sitting on the edge of the bank, slapping his cheeks like a lunatic and crying out, 'O my misfortune!' The engineer anticipated so severe a punishment that fear had petrified him into stupidity. I remember that my predecessor at the Barrage refused to compliment me on the success of the first year's experiment. The reason he gave was that I had undertaken the experiment with only the prospect before me of a return to India in case of failure; while the prospect before him would have been a permanent sojourn at Fashoda. He added that if I had been in his position I should have done exactly the same as he had done, viz. drawn my salary and run no risks."

Examination may be made of Tables 84, 86, and 87 for the 1892 gauges at Aswan, Assiut, and Cairo; of Table 89 for the 1878 gauges at Khartoum; of figs. 15, 16, and 17 for high-flood gauge diagrams at Khartoum, Aswan, and Cairo; of Table 91 for high-flood gauges at Cairo; and of Table 192 for high-flood gauges at the Delta Barrage.

108. **Nile Bank Protection.**—We continue the quotation from the second edition of this work:—

"The mistake the Government has made in the past has been to economise in stores and materials, which are most valuable but which have to be paid for. They at the same time have made up for this economy when a really dangerous flood has been on the country, by sending two men on the bank where one has been

needed, because the men have not to be paid for. If every second man had been allowed to redeem himself for a trifling sum of money, and the ransom money had been spent in purchasing materials, the engineers would have been far better able to cope with the floods.

During floods the Nile banks are covered with booths at intervals of from 50 to 150 metres, according to the amount of danger incurred. In each booth are two watchmen, while in addition to the above, every really dangerous spot has a special gang of from 50 to 100 men. When the Cairo gauge passes R.L. 20·05 metres the number of the corvée is doubled, and the men have to bring with them additional brushwood and Indian-corn stalks, as the early protective works are being drowned out, and the Nile is rising against the unprotected parts of the banks.

The following memoranda were made during the floods of 1887, 1892, and 1894.

1. *The Use of Sand-Bags.*—The operations during flood have disclosed the great value of sand-bags. They are easily transported; quickly filled with earth and deposited in place; make a good join with an earthen bank; thrown into deep water, will stand nearly perpendicular if the bank needs to be raised quickly; form a bank practically water-tight; are very cheap compared with stone. Twine and packing-needles should always accompany the bags.

Cotton-seed sacks, $2\frac{1}{2}$ piastres each, are the most economical, and are also easily handled. In using them in running water, a row of stakes should always be driven in, as they prevent the first sacks from rolling; once some fifty sacks are in position the rest do not roll, but stay where thrown. For the efficient use of sand-bags, the banks should everywhere be 1 metre above maximum flood; this permits of taking earth from the top of the bank and quickly filling the sacks and staunching the breach, when there is nothing but water on both sides of the bank; this is a point of very great importance, as at the beginning of a breach time is everything. Sacks should never be filled with sand and left as reserve, as the dampness destroys them; fill them when needed.

2 *Protection of Banks during Floods.*—If a bank is being eaten away in front and there is no infiltration through the bank, a 'banquette' is advisable. If,

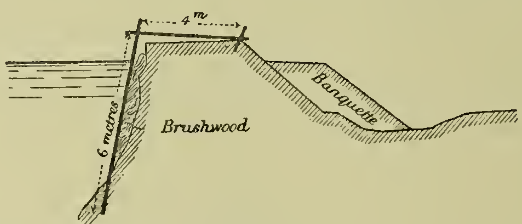


FIG. 89.

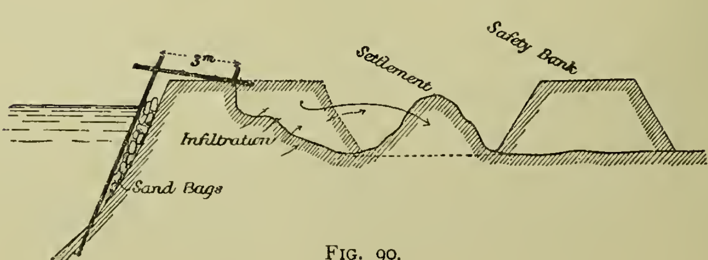


FIG. 90.

however, the bank has slipped badly on its reverse slope owing to infiltrations, earth should be thrown on the river side if there is any berm; if there is no berm a safety bank should be thrown up, and stakes supporting sand-bags be driven in on the river face. 'Banquettes' under these circumstances have done more to endanger the banks than the action of the river itself where the current is very severe. A few bushy trees thrown into the water, with some sand-bags tied to the branches to weigh them down, and a few boats laden with earth moored over the trees, protect the bank temporarily, until some more permanent work can be undertaken.

3. *Protection from the Wash of the Waves.*—The ordinary protection of banks by vertical stakes (generally $4\frac{1}{2}$ to 5 metres long) tied or nailed together, and packed

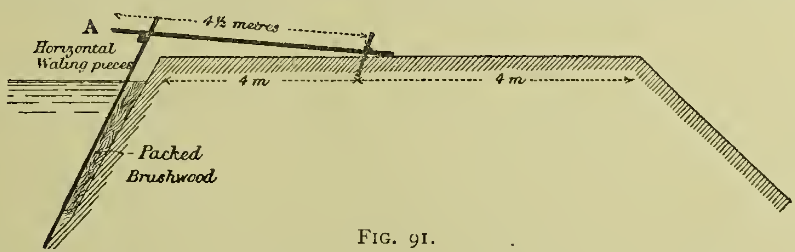


FIG. 91.

behind with Indian-corn stalks and brushwood, is well adapted to save banks from the wash of the waves.

4. *Treatment of Safety Bank.*—No safety bank should be allowed to stand a single year without being subjected to water pressure. High-flood water coming on these new banks for the first time is disastrous. Cuts should be made at

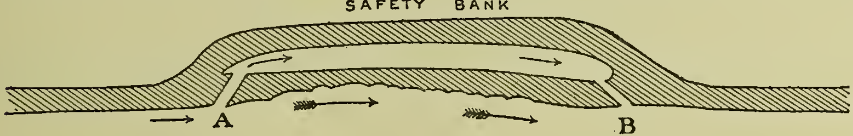


FIG. 92.

A and B before the flood, which may be closed when the Nile is very high; they should be opened again when the Nile begins to fall. This not only consolidates the banks, but fills the pits with clay.

5. *Treatment of Culverts.*—All culverts should be provided with clay banks in front of them, as in the following sketch. If the culvert is to be left open, a wooden

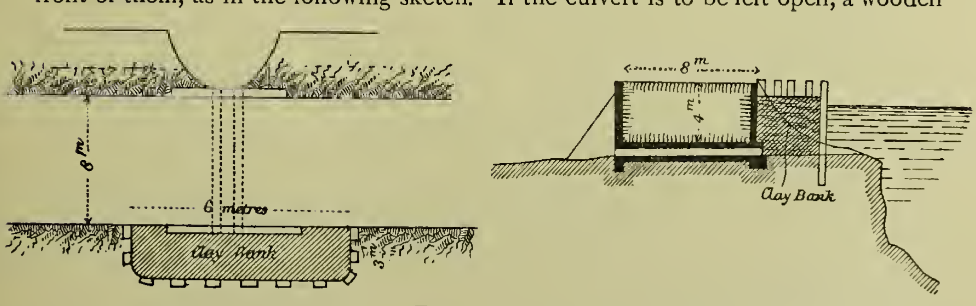


FIG. 93.

shoot can be run through the clay bank. The clay bank should keep pace with the rising flood.

These banks cost £·50 per culvert, when very well done, and render the worst culvert harmless. In the dangerous places there are about six culverts per kilometre.

6. *Sharp Bends of the River.*—When the river rises in high flood above its ordinary channel it has a habit of cutting sharp round some corners, such as C, where the soil is always sandy, and where a breach would soon assume very serious proportions. No bends of this kind should be unprovided with a safety bank, such as A B.

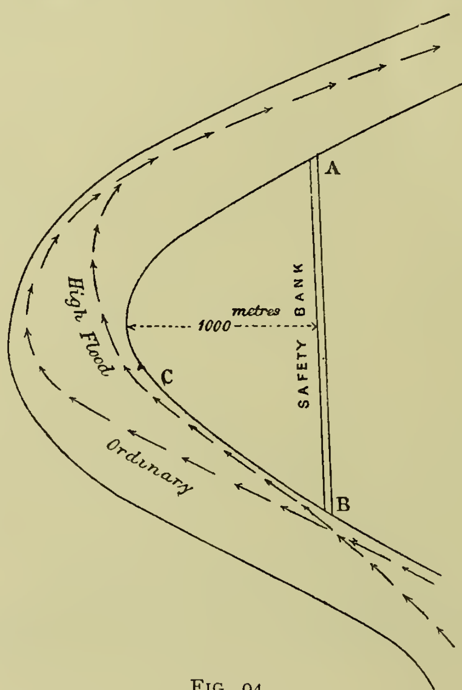


Fig. 94.

The following estimate was made of the cost of protecting the provinces of Menufia and Gharbia from inundation during the high flood of 1887.

Cost of Nile Protection for 432 Kilos, or 1,200,000 Acres.

Materials Paid for.	
Sand-bags utilised, 60,000 at £·03	£1,800
Stone (cubic metres) 5,000 at ·50	2,500
Stakes 55,000 at ·06	3,300
	£7,600
Materials Unpaid for.	
Camel loads of stalk for 42 kilos, 14,000 at £·15 each	£2,100
Total materials	£9,700
Boat Hire and Contingencies.	
15 engineers at £80	£1,200
Corvée, 1,374,079 men at £·03	£41,222
Labour and materials, total	£52,122

Therefore: cost of protection per kilometre of bank = £120, and per acre = £·045.

If the cultivated area of Lower Egypt be taken as 2,750,000 acres, the cost of protecting the country came to £123,750, of which sum Government paid £26,000, and the fellahin did work representing £97,750.

Sir Colin Moncrieff, in his note on the Nile flood of 1887, says :—

'On the 10th September an important decree was issued that whenever the Nile had reached R.L. 20·05 metres on the Cairo gauge, all persons fit for work, of whatever rank or station, should be liable to give their help in protecting the banks. This law was of some use; but, as heretofore, there is no doubt the burden of protecting the country from inundation fell chiefly on the poor, and the sentiment of "Noblesse oblige" was conspicuous by its absence among the rich and powerful proprietors.'

After the flood of 1887 the permission of the Government was obtained to protect, in 1888, the 50 kilometres of the Rosetta branch north of Kafr Zayat by contract and not by corvée labour and materials. The experiment was eminently successful as far as the work of protecting the banks with stakes and brushwood and guarding these was concerned, but as the flood unfortunately turned out to be an insignificant one no conclusions could be made. It may be stated here that the Nile protection corvée still exists in spite of periodical efforts and experiments to prove the practicability of abolishing it in ordinary floods. The Irrigation Department might begin to take upon itself the duty of protecting and guarding the banks while the Cairo gauge was below R.L. 19·50 (23 cubits), and call the corvée out when that figure was passed. The work of staking and protecting with brushwood, and the provision of both stakes and brushwood might certainly be performed by the Government, whether the guardians were paid for or not paid for.

During the winter of 1890–91 I had an opportunity of examining the works in the valley of the Po, in Italy, and extract the following data from my note-book :—

'Near Ferrara the Po was in very heavy embankment. The section of the bank was as follows :—

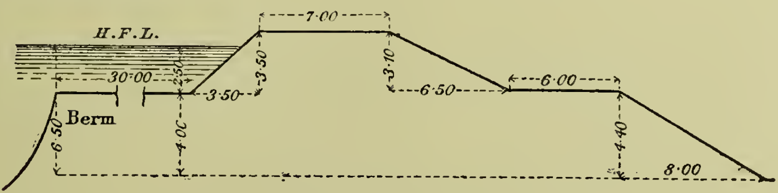


Fig. 95.

There was a carriageway on the top of the bank, while the slopes and banquette were beautifully turfed. Nothing short of these splendid banks could give security to the low-lying villages and thickly inhabited country round Ferrara

At every 100 metres or so along the bank was a platform 4·00 × 3·00 metres, projecting beyond the line of the outer edge of the bank. At each platform was a stone post with a number on it. These platforms were the stations of the guardians who were called out during dangerous floods. See fig. 96.

An engineer riding or driving down the bank could note in an instant the numbers of the guardians who were absent from their posts, and report the matter to the proper authorities. It struck me that we might imitate the Italians in this matter with great advantage.

At the Viloresi Canal head, on the Ticino, near Milan, I noticed that in an

exceedingly swift velocity on a coarse shingle bed the engineers had trained the river by means of boulders packed inside galvanised wire nets of a cylindrical form, each 3 metres long by 2 metres diameter. The meshes were 16 centimetres square, and the thickness of the wire 3 millimetres. Each wire net weighed 35 kilograms, and, including cost of filling with stone and putting into place, cost £1. While watching the operation it struck me that these wire nets were far superior and infinitely more suitable for lowering stones down a dangerous slope in flood time, or

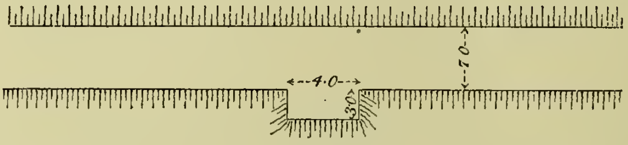


FIG. 96.

closing a breach, than the ordinary palm fibre nets, or "shinfs," which have no power of resistance.'"

In Mesopotamia wire gabions or "sausages" filled with stone and brick were tried and found very successful. The ordinary length was 15 metres, and the diameter 1·5 metres. There is a very good description of these sausages or wire gabions in the *Minutes of the Proceedings of the Institution of Civil Engineers* (London), in a paper by Mr Anderson of the Eastern Bengal Railway in Silhet.

Since 1906 very liberal sums have been allowed for protecting the banks of the Nile to guard against flood. This money is mainly spent on spurs and revetment in places. We give the sums spent during the last years of which the reports have been published and compare them with 1904, an ordinary year, before the liberal sums began to be granted.

TABLE 215.—ANNUAL EXPENDITURE ON NILE SPURS.

Year.	Expenditure in £.		
	Upper Egypt.	Lower Egypt.	Egypt.
1904	6,000	30,000	36,000
1906	10,000	92,000	102,000
1907	20,000	71,000	91,000
1908	24,000	71,000	95,000
1909	27,000	110,000	137,000
1910	30,000	35,000	65,000

109. **Silt Deposits in Canals.**—As the Nile in flood time is heavily charged with sediment that settles in certain canals and causes the silt deposits which are so important a factor in the economy of perennial irrigation, we have considered it convenient to treat the subject in this chapter. We shall begin by giving an interesting letter which was written

by Mr P. Claxton of the Punjab Irrigation Service to *Indian Engineering*, and which appeared on the 10th September 1910. It was written in answer to a letter of Sir William Willcocks to the paper forwarding the proposed design for the Hilla branch head on the Euphrates and inviting engineers to criticise it.

"The silt carried in rivers is not borne steadily onward, but by continual removals. Most of it is scoured from the neighbouring banks and is not brought down from any distance. Scoured materials cannot be carried across a stream, but are deposited a short distance lower down *on the same side* from which they have been borne. The above remarks will help us to understand the general tortuous course of a river given in fig. 97.

Starting from a point A and considering only the right side of the stream, we have a scour along the right bank, beginning at A and ceasing at B. At A the water is clear, while at B it is most heavily laden by the scoured material from above. In fact the point B may easily be supposed to be determined by the amount of silt in suspension. When this reaches the limit the velocity can carry, a

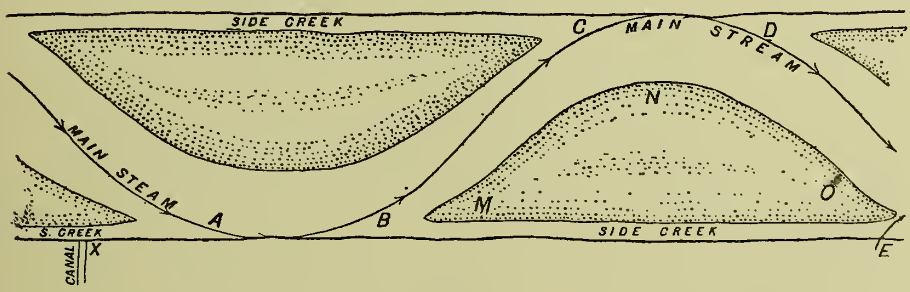


FIG. 97.

deposit begins, while the main current passes over to the left. In doing so the velocity of the stream on the right diminishes and the deposit increases and spreads out in an island. After most of the silt has thus been deposited on the right, the island again narrows till at E the water is clear and the conditions are again as at A. The island M N O may be considered to be a rough measure of the scour above along A B. Similar actions may be traced on the left bank. At every point on a river or on any of its branches these conditions may readily be recognised, though modified in numerous ways.

Now, to choose a successful head for an inundation canal the one point to be borne in mind is to place the off-take in clear water. Referring again to the diagram, any head placed between A and B would silt, as this water is heavily silt-laden, but no shoal would form before the head. At B, and a little lower down, the head would silt and leave a shoal forming at its mouth. The only other point is above A. This is invariably the best selection. Usually also it is favoured by the clear outfall of a creek, and a short distance up this creek at X is the ideal point.

Thus it will be understood why a back-water intake is so often chosen, though all the reasons of choice may not clearly be known. This fact of itself suggests a retreating loop for a canal head. It is of importance, as there is no doubt that such

an intake has a tendency to reduce silt. This leads us to a consideration of the reluctance of silting in a back-water intake.

In noticing the formation of natural channels the shoaling shown on fig. 98 may be observed. The successive formations have been numbered in order. Thus the shoal extends downward from A to form an apron before the intake. At B there is slight cutting, and at C slight shoaling. This will in time reach a limit till the characteristic loop is formed, after which the canal will maintain a clear intake with apparently little change. The formation at the head now involves a turn-about of flow, in performing which the heavier silt, by reason of its greater momentum, is carried past the intake. Meanwhile the lighter, more adaptable clear water has filled the mouth and offers a cushion of resistance which excludes more. The excess pressing in is thrown back upon itself and carried along as indicated by arrow-heads. Thus the loop brings about back-water conditions at the intake, which causes *silt separation.* This is dealt with more fully below.

Sir W. Willcocks' spur (fig. 99) is meant to take the place of the shoal. My first design contemplated a more extended apron wall. By building an inclined

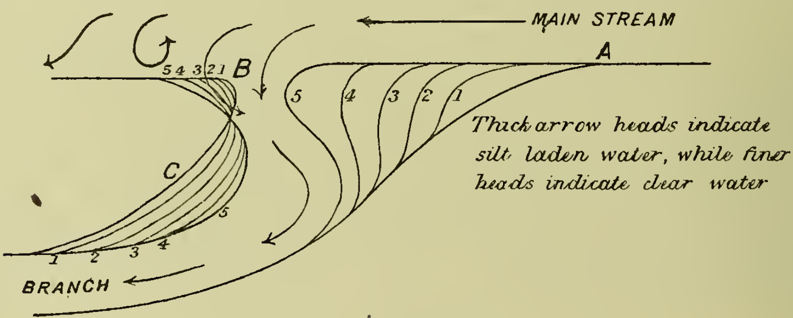


FIG. 98.

spur, however, as shown in thick lines and arrows in his original drawing, a new principle is introduced which is of considerable importance. This leads to the study of the effect of a plane placed in a stream inclined outward to the axis. See fig. 100.

It interested me sufficiently to carry out some actual experiments. I found that such a plane caused heading up all along its face, which produced a strong outward thrust, as indicated by arrow-heads. This effectually threw off all rubbish and cleared the water considerably within the thick dotted line which marked distinct dirty water. At the same time a thin stream clung close to the wall with increased velocity. In fact, the highest ridge of water, dotted *a b* is a short distance from the wall. All rubbish falling within the ridge would be swept along and round the end of the wall into the branch. To exclude this, but more particularly to break long lateral scour, groins may be introduced as shown in his drawing.

Such a wall is really a silt separator; but, besides clearing the water at intake, it has another advantage. This is the protection it affords the upper sluices. No logs or heavy material can approach the head closer than the outer dotted line, but will be pushed outward round and past the head. See fig. 100.

If after separation an undesirable amount of silt still enters the head, another device for further clearing the water is shown in the form of a loop channel. This

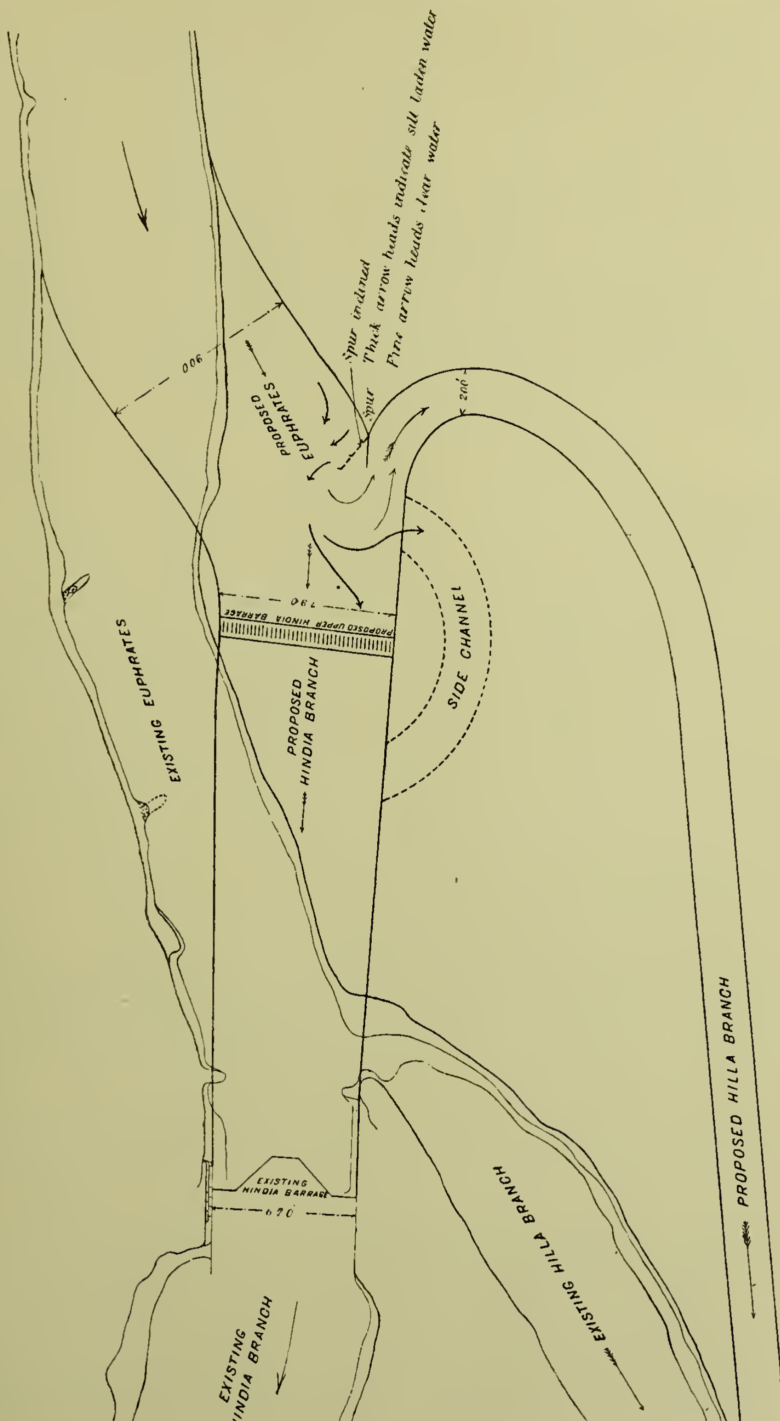


FIG. 99.—Plan of the Euphrates at the Hindia Barrages (Existing and Proposed). Approx. Scale $\frac{1}{10,000}$.
The side channel shown in dotted lines proposed by Mr Claxton.

should recommend itself, and will readily be understood. Being the more direct course, it will draw off the greater part of the silt and discharge it below the Barrage. By giving a steep slope, a high velocity may be arranged which will make its working more effectual.

The conclusions thus are that a retreating loop offtake has a tendency to reduce silting in the branch. This is borne out by the reluctance of formations in backwater intakes of inundation canals and of natural channels. A more weighty consideration, however, is the location of the intake which must draw from clear water. No natural channel could exist with unfavourable conditions at the heads. It is possible to make the best selection for permanent canal head as for inundation heads, but to maintain the conditions would be expensive. A modification, however, or a non-silting head seems quite possible. In its design a new principle is introduced, viz., *silt separation,* which appears to have nowhere been applied."

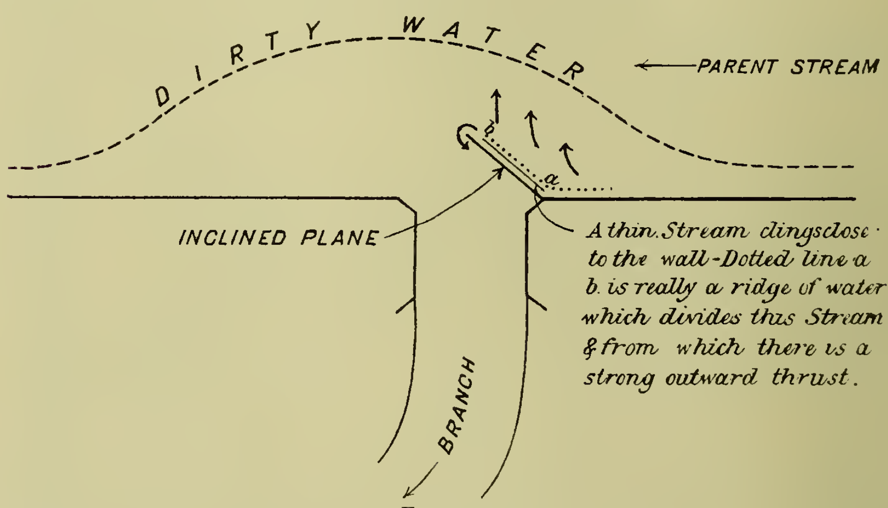


FIG. 100.

The following quotations from the *Irrigation of Mesopotamia* will explain how it is proposed to deal with the silt question on the Euphrates and Tigris. They are applicable to all rivers heavily charged with sediment. It will be noted that the canals take off backwards from the river, as in fig. 99:—

" It will be seen from the drawings that I have chosen the Egyptian system of barrage for all the works in Mesopotamia. I have done this for three special reasons :—

(1) Such a barrage will be capable of being fully opened in flood and not causing any rise of the river in a country where any rise would be disastrous.

(2) The Tigris and Euphrates floods are not gradual, but consist of a series of rapid rises and falls. Now, at the crest of the rise the quantity of deposit carried by the river is extraordinarily great. During a rapid rise in winter the matter carried in suspension may amount to 750 parts in 100,000, or five times the maximum of the Nile. Four days afterwards the quantity may fall to 140 parts in 100,000. Now, there can be no doubt that the complete obliteration of the

ancient canals was due to these heavy deposits. All the canals took off the Euphrates without weirs; and while they were veritable rivers themselves, they preserved their sections (for depth gives velocity as readily as slope does); but when in troublous times they began to be neglected and silt their beds, they became like the small canals of to-day, incapable of taking the less muddy waters of the falling floods or the clear waters of the low supplies, and had to content themselves with the muddy waters of the crests of the rises of the river, which gradually choked them up and ended by absolutely obliterating them. One has only to see the Hilla branch to understand how fast this obliteration can proceed. To obviate these disadvantages, it will be essential for all canals to take off from above Egyptian barrages. When a rising flood surcharged with suspended matter is coming down, the barrage will be fully opened and the canal head closed. In this way the canals will be free of the heavily charged waters of the rivers; and to enable their regulating heads to keep out the floods I have designed them with very massive foundations.

(3) It is a well-known fact that the mass of the heavy sediment carried by a river is to be found where the velocity of the river is greatest, and that the slack water is comparatively free of this deposit. I have already stated that during the times of very heavy deposit the canal heads will be closed, but there will be a considerable amount of sediment when the floods have fallen and the canals are open. An Egyptian barrage will allow us to close the openings near the canal head and so force the heavy current to the other side of the river. By judiciously placing spurs upstream of the canals and taking the canals themselves backwards, as will be clearly seen in fig. 99, it will be possible to make doubly sure of letting a minimum of deposit enter the canals when they are open.

If the works answer the purpose for which they are designed, we may contemplate the introduction of irrigation into the Delta of the Euphrates and Tigris without the anxieties which beset the ancients, according to their own historians.

The second system of canals taking off from the Feluja Barrage will be the left Euphrates canal system. The feeder will follow the left bank of the Euphrates from the Abu Goraib head to the Iskandaria Canal head. The area commanded will be 650,000 acres. This feeder will provide water in times of low supply to the Abu Goraib, Radwania, Nahr Melcha, Mahmudia, Latifia, Kutha, Babylon, and Iskandaria Canals. During the floods, the same canals will be fed directly from the Euphrates and taken under the left Euphrates canal by means of iron pipe syphons. Pipe crossings will also be provided for flood irrigation on the existing watercourses. In this way the main canal will be kept from silting up and the country will not be deprived of the muddy flood waters so necessary for agriculture.

An examination of the drawings will show how massive are the foundations which have been provided to allow of the main feeder canal head being closed in full flood whenever the water is heavily charged with sediment."

Subsequently to this we received a series of observations on silt movements and erosion in rivers from Mr P. Claxton which interested us greatly, and we insert them as they open up interesting questions and suggest methods of silt prevention which might be experimented on in models, as suggested before.

We consider that it is wise so to regulate the entry of silty water into a canal head on a river that the water enters the canal laden with just so much silt as the canal and its branches can carry on. If the silt entering the minor canals were reduced at every minor canal head, the water eventually left in the main canal would be pea soup. Once the silt has entered the canal, every minor must take its share, unless there are scouring sluices.

Mr Claxton writes :—

"The broad principle of silting is dependent on two factors: the current of the stream and the amount of the silt in suspension. These two, acting and reacting on each other, carry on the formations in a river which is continually wearing away its bank and depositing it again. This gives the characteristic tortuous course. Silt is never carried forward steadily, but by successive removals. It is worn at one bank along which the river sets, and when the velocity exceeds the critical for the nature of the soil, the water becomes very heavily laden. When the limit is reached a shoal begins to be deposited, the main current crossing over to the other bank. Thus the river takes the general form shown in fig. 97.

The action of river scour and deposit may be observed on a smaller scale in canals, especially inundation canals. Where the banks happen to be excessively eroded, soundings have indicated a shoal below, but this has been found to be shifting. In the case of rivers the stream has the option of going round a shoal. In a canal it must scour it out. The abnormally heavy-laden water resulting from the action cannot carry the silt forward to any distance, but deposits it again immediately lower down—we thus have the travel of a shoal downstream. In one instance the effect of such a shoal passing a distributary head (the Atari on the Katora Canal) was observed by me. The distributary silted up most unexpectedly in a very short time. It will be readily understood by this that were heavily silt-laden water to pass a canal head, the latter would quickly become choked.

Studying the illustration of the river (fig. 97), it will be seen that we have deeps A–B, C–D, occurring alternately with bars B–C, D–E. There is scour of the bank along the length A–B, C–D, the silt being deposited immediately below, forming the islands indicated. To understand the conditions more exactly, it should be noted that silt cannot be carried across the current of the stream.* If it is scoured on the right, it will be deposited only on that side. The point B may be expected to depend on the amount of the silt in suspension, which again depends on the nature of the bank scoured. The silt first begins to deposit gradually as the right velocity at B is great; but as the main current passes to the left bank, the water of the right spreads out and the deposit becomes broad and heavy. It again begins to narrow and lessen, and the water clears till at E it is again most clear, the stream leaving an island which roughly measures the amount of scour in the reach above. This is only for the right side. On the left the conditions are different, the water being clearest at C and foulest at D. Thus we may conclude that the water of the river

* We note that this statement is contrary to the observation and experiments of Professor J. Thomson at bends. But as Mr Claxton is a practical man who observes and thinks, we leave his observations as he wrote them.

is never equally silt-laden in any normal cross-section, and the variations tend to be markedly different at either extremity. Considering the right side only, the water is most clear, as stated, at A and E. At B it will be most heavily silt-laden. Thus A and E would suggest themselves as favourable heads, and B as the worst possible. This is actually the case. The best position for the head is slightly above A, *i.e.* above the point where the scours begins. This is usually favoured by the outfall of a creek, the most ideal head being a little up the creek at X.

This creek, it should be remarked, does not readily silt from below, and any formation that may occur does not extend up the creek, but is confined to the outfall. The water entering the creek at the intake will of course clear this out again as soon as the river rises high enough, but when there is the draw of a canal, this of itself should keep the outfall clear with only a low bar at the mouth.

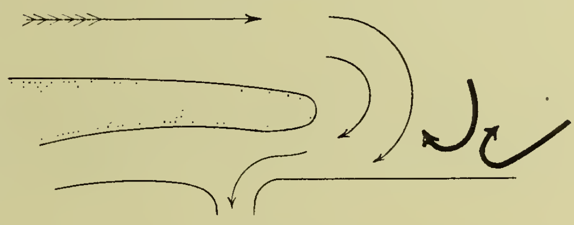


FIG. 101.

Considering the case of the ideal heads for inundation canals, it is evident that silting forms reluctantly in a backwater intake. Also the draw of the canal head keeps this intake clear, with the exception of a low bar at the mouth. The reason for the reluctance of silt to enter the canal under such circumstances may be ascribed to the momentum of its particles. In such a case, where the stream is made to turn right about, the heavy particles of the silt will do so more reluctantly than the easily adaptable water. They are consequently carried past, while clear water enters the intake. To put it more exactly, a sketch will be necessary. The light arrows indicate the clear water—the broad that silt-laden. The clear water, it will be seen, enters the backwater creek, but the heavy-laden water, which comes round in wider circles, is turned about on itself, owing to the heading up of the excess pressing into the creek.

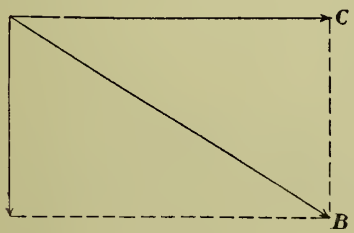


FIG. 102.

This knowledge makes the basis of design suggested for permanent heads; but before going on to it, it will be necessary to attempt to set forth something of a theory for the passage of silt through water.

Taking the forces which ordinarily impel each particle of silt, we have (fig. 102) the difference of the weight of the particle and its buoyancy drawing it downward and the current C impelling it forward. The current may be considered horizontal. These two forces would give a resultant B, which would in the ordinary course of events carry the particle of silt to the bed of channel at B; its momentum and the continued action of the stream roll it along, till, with other neighbouring particles, it reaches C (fig. 103), where an excessive accumulation results. The accumula-tion increases the lower surface velocity of the water and occasions a slight scour. The particle is again lifted, only to be deposited again and rolled and scoured

along by several removals till it finds a resting-place at length. This action produces the characteristic wavy beds of channels in general.

It will be seen that the greater the velocity the more horizontal will the lines of motion become, the more vigorous the scour, and the higher the resulting flow of

FIG. 103.

silt. As the velocity subsides, the silt also does so, and the heavier particles flow close to the bed. This action does not consider the effect of outside eddies, which also contribute something to the silt distribution. Any sudden change or obstructions in the bed or at the side would raise the particles abnormally high.

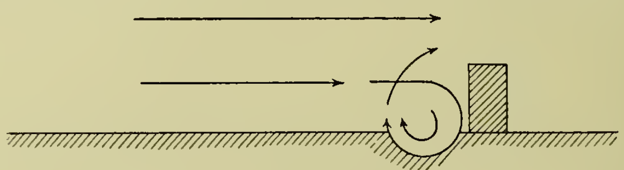


FIG. 104.

In the bed this action, as illustrated in fig. 104, often forms a hole above a weir or crest. Obstructions at the sides also cause a bed scour by the action due to the increased velocity. As the banks are usually stiff enough to resist erosion, the scour takes place in the bed.

The conditions which usually prevail at regulators are a heading up of the supply

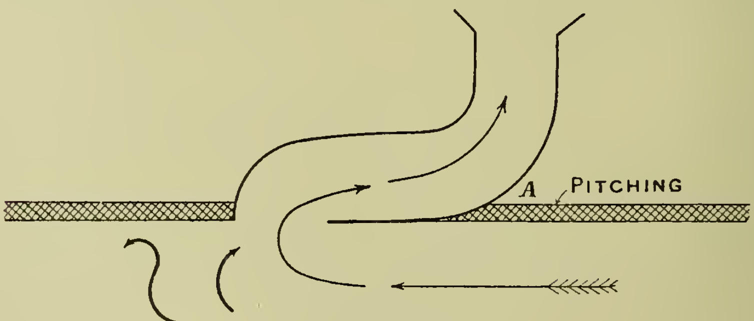


FIG. 105.

with a corresponding decrease in velocity and consequently lower flow of silt. These conditions should be favourable for the off-take of a distributary branch. That this is actually the case has been observed by me in some striking cases.

Supposing conditions of this nature, the head suggested may be of the form shown in fig. 105. It will be seen that the ideal conditions for an inundation canal head are secured by an outer curtain wall with an intake well below the distributary head. As noted, a bar may be expected to form at the mouth of the

intake, but the draw of the branch will keep this low. The bar will be an advantage in checking any inflow of the heavier silt. In case, however, this becomes troublesome, a gate may be added at A, which, when opened (the distributary branch being closed), will scour out what deposit may have formed. See fig. 105.

But these conditions may be improved by a somewhat novel method. The advantage is gained in increasing the velocity of the parent stream to make it much greater than that of its branch. This is done by restricting the water-way of the former as shown in fig. 106.

The momentum of the particles of silt will now be greater, and they will consequently be carried past the intake more effectually. Another consideration is the reaction of the slow flow in the intake on the main stream. The greater the difference in velocity of the two, the nearer do we approach to the conditions of a dead cushion of water at the intake. This may be expected to check the inflow of the silt; a disadvantage in restricting the main channel which should be noticed is the higher flow of silt causing heavy particles to rise above their normal height."

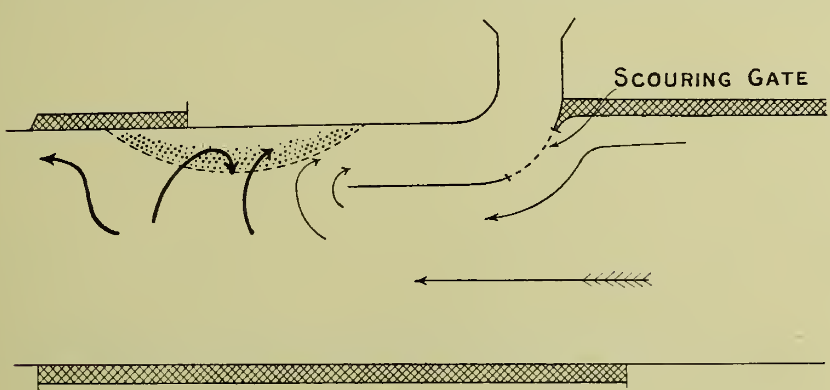


Fig. 106.

"It may be demonstrated that the winding of a river is not due to the necessity of lengthening its course to co-ordinate its velocity to the resistance of the banks, for it should rather widen its banks to attain this result. The tortuous course is undoubtedly the result of varying densities of silt borne in suspension. This is the greatest factor in river changes, and compels a tortuous course. How these conditions came about is explained by the existence of unceasing forces all along the stream, which contribute their effect, and which are brought about by the very irregularities they produce. To understand what goes on, one must remember that material borne in suspension has considerable weight and is more inert than the medium through which it travels. It therefore must soon come to the bed after being lifted in suspension. In motion it acquired a momentum which resists change more than the supporting medium, and the formation of deposits may thus produce results which are characteristically curious. One of these is illustrated in the formation of creeks. The well-known backwater intake is the chief feature, and its formation is deserving of notice. At the outset the creek is a wide direct channel, but very soon deposits 1, 2, 3, 4, 5 begin to form at A and B with corresponding slight cutting at C. (See fig. 98.)

After a time a limit is reached beyond which changes are very slow, and the

creek continues to draw fairly clear water. To explain these actions, it should be noted that the direct wide mouth causes an indraw of silt, represented by an inward inclination of the plane beyond the zero pressure limit. This causes silting at A. The heaviest silt is laid down first along A_1, and, the water entering the creek having in consequence cleared somewhat, clearer water continues to be drawn in over the rest of the mouth till in turn A_2, A_3, A_4, and A_5 are silted. Thus a spur is formed, compelling the water to take a turn-about in a backward direction into the creek. The cutting at C is very small and may be neglected. The silting at B is also inconsiderable, being the amount taken in excess by the least cleared side of the entrant water, *i.e.* the side which has dropped no silt at A. Now, as the entrance becomes more and more looped back, a new principle seems to come into action. The increasing loop requires a more complete turn-about of flow. If, then, it is borne in mind that the silt is heavier and more inert than water, it will be understood that it is slower in conforming with changes of directions than the mobile medium in which it travels. Thus there is an increasing tendency for its being carried past the mouth of the creek before it can alter its direction to make a complete turn-about. Meanwhile the more adaptable clearer water has filled the mouth and excludes the dirtier water as indicated by arrow-heads. The tendency increases so long as the shoal from A advances across the mouth, the jump across of dirtier water also increasing in volume till a limit is reached for the time. The limit of reversions of intake may be determined for any grade of silt with which it will vary.

The process brought into action at the mouth of the creek may be termed *silt separation*, and is extremely important, as it has many suggestions for non-silting intakes. In combination with an inclined plane, shown in figs. 99 and 100, which is a silt separator, a design for a canal head seems possible for the exclusion of silt.

We should get the notion out of our minds that velocity in a stream is the direct agent governing its formations. It is only when its energy is changed into other forms that the effect of velocity is applicable. There is nothing in the velocity, for instance, to hold a particle of silt in suspension. The velocity has no vertical component to counteract the weight, and the particle must soon come to rest at the bottom of the stream. The lifting power of streams is the vertical component of eddies. Again, it is the friction set up by the flowing water which is the initial motive power. This has not been noted before. A bank which offers a cutting surface is worn down by the friction of direct flow and the swirl of eddies set up by the irregularities of the bank. The action of direct flow along the side of a bank has hitherto been neglected. It is, however, a powerful agent of erosion in combination with eddies. On the bed friction rolls the particles of silt along the bed, but does not raise them, unless irregularities of bottom offer cutting edges bringing about the formation of eddies in combination with the action of friction. Thus the initial motive power is friction and the lifting power the upward vertical component of eddies. The energy of velocity merely directs the motion of a particle that has been moved and lifted and ceases to act when the particle is borne to the bed."

We have given Mr Claxton's views exactly as he has expressed them ; many, however, hold that, though on straight reaches scoured material does not cross the river, it does cross on bends, especially severe bends.

E. H. Hooker (*Trans. Amer. Soc. C.E.*, xxxvi., 1896) has entered into

the subject with great detail, and we content ourselves with a very brief résumé of his results. The specific gravity of Nile silt being about 2·0 on the average, it is found that particles of various size will be maintained at a uniform height above the bed of the stream as follows:—

Diameters of the grains . mm.	0·2	0·4	0·6	0·8	1·0	2	3	4	5
Vertical velocity of equilibrium, centimetres per second	3·0	4·0	5·7	7·0	8·2	12·3	14·4	15·4	17·3

J. B. Francis, by observing the distance at which colouring matter, liberated at the bed of a stream, reached the surface, inferred that there existed an upward velocity of from $\frac{1}{10}$th to $\frac{1}{30}$th of that of the stream (applicable, of course, to half the water, as the other half must have moved downwards with equal velocity). In the Nile in flood there must, therefore, exist upward velocities capable of supporting silt up to at least 0·6 millimetre; and locally, where there are eddies, even larger or more numerous grains may be carried.

Having given Mr Claxton's instructive views, we may add here the views held by other observers:—

"In nature perfect equilibrium is unusual. What is commoner, may be more in accord with fact, is oscillation about a state of motion near the position of

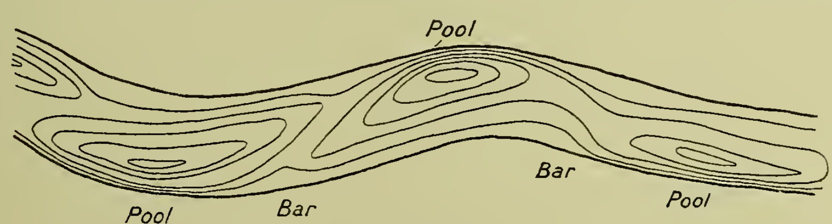


Fig. 107.

equilibrium, and this is the case here. The silt density which is proper to the conditions at one point is supersaturated for another point further on, and deposit takes place. The water then moves to a point where from local circumstances it is unsaturated, and scour occurs until there is again local saturation. And so the process goes on, and there results an alteration of bars and pools down the watercourse. In conformity with the same principle, the current itself swings from side to side of the equilibrium position, with the result that the bars and pools succeed one another in echelon and not in strict series (fig. 107).

The material deposited on the bars is rolled into the pools, where the increased turbulence causes it to be again taken into suspension, again to be deposited on the next bar, and so on. From this description it is clear that the velocity of the suspended matter is not necessarily the same as that of the water, but probably much less. Hence the calculations made above must be regarded as approximations to the upper limit of the silt discharge. That form of the bed which is stationary or stable for a particular stage of the river is unstable in another, and gives place to the form proper to the new stage. So in flood the bars are

scoured and the grade of the bed becomes more nearly uniform. This scouring is more active during high floods than during low ones, and works in the direction of increased security to the banks. Thus calculations based on the difference of flood volume show that Khartoum ought to have been flooded during the high flood of 1878, whereas the water certainly never reached the crest of the bank. The flood of 1906, following on a long series of low floods when the bed had not been scoured, threatened to overwhelm the town, but the danger passed. The excess of the flood of 1878 over that of 1906 was so great that flooding must have ensued but for some such erosion as we have described."

110. **Silt Deposits in Canals in Egypt.**—Now that the Ibrahimia Canal takes out from above the Assiut Barrage, the silt clearance of this canal is a simple matter; but in pre-barrage days the canal was an interesting example of a great reduction of silt deposit in the canal by means of spurs put in by Major (now Sir Hanbury) Brown opposite each other at regular intervals down the whole length of the canal above the Deirût regulator. The following quotation is from the second edition of this work:—

"The cost of silt clearance of the Ibrahimia Canal has, as already stated, been no inconsiderable item in the budget of the Fourth Circle of Irrigation, and its reduction has engaged the most serious attention of the irrigation officers. Sir Colin Scott-Moncrieff, in the Report of 1887, wrote as follows:—

'As stated in former Reports, the chief source of expense on the Ibrahimia Canal is dredging. The following figures show the progress made in reducing it:—

—	Cubic metres dredged.			Expense.
	Assiut to Deirût.	Below Deirût.	Total.	
1884	817,430	330,260	1,147,690	£34,656
1885	604,598	182,314	786,912	35,662
1886	461,363	...	461,363	24,429
1887	523,410	...	523,410	26,124

'In former Reports it has been shown how dredging is no longer required in the Ibrahimia Canal north of Deirût, and in the Report for 1886 it was stated that to diminish the dredging south of this point, Captain Brown had been narrowing the bed of the canal by placing in it a series of stone groynes or spurs. He erected 12 pairs of these groynes in 1886 at a cost of £2108. In 1887 he erected 14 pairs and repaired former ones at a cost of £2403. The result has been very satisfactory. The heavy dredging formerly necessary north of Manfalut will probably not be required again, and when the spurs are erected along all the portions requiring dredging, we may hope to reduce it to a very small volume.'

In the Report of 1891 Major Brown writes of these spurs as follows:—

'There is now a continuous line of spurs from 2¼ kilometres to 34 kilometres. They have not, however, prevented all silting in this length, as in January 1892, as

stated above, there are two heaps about a kilometre each in length, about kilometres 12 and 27, from 3 to 2½ metres above proper bed-level, which will have to be dredged. A longitudinal section taken out the 2nd January 1892, before commencing dredging, is sent with this Report. I think it probable that these two heaps in the line of spurs are due to the large amount of material dredged last year from the 5th to the 10th kilometre, which has been brought back from the berms where it was deposited into the channel. If this is the true cause, there are greater hopes that these high parts will not be found to have re-formed after next floods, or at any rate that they be formed lower down the canal and in less quantity in consequence of this year's dredged material returning to the channel. There were 32 pairs of new spurs made in 1891. The following is the account under the head of Ibrahimia Defence works:—

	Cubic metres.	£
32 pairs of spurs	14,284	2507
Repairs to old spurs	1,982	295
Railway revetments	2,226	254
Protecting special points	1,796	230
Total		£3286'

In the Report for 1892 Major Brown writes as follows:—

'The spurs built in 1891 kept the bed clear over the length spurred, where dredging had been necessary the year before. There was less deposit found in the bed after the flood, and dredging downstream was forbidden. For these two reasons the dredging bill was the lightest there has been since dredging has been done by contract. The prospects of 1893 are that the cube to be dredged will nearly, but not quite, come up to the figure of 1892. For the first time, the contractors have not been given the usual notice, according to the terms of their contract, that the cube to be dredged will exceed 400,000 cubic metres.

'On page 78 of last year's Irrigation Report, Colonel Ross proposes, that, with the view of decreasing deposit in the Ibrahimia, the water level at Deirût regulators should be held up as much as possible to decrease the velocity of flow in the canal, and so counteract the tendency of high velocities to scour the sides, and bring material from them into the channel. That this action goes on is undoubted, but not at the time when Colonel Ross supposes. It takes place at the height of the flood, when the regulators at Deirût are open, but still with the water level there at the highest safe limit. There is no possibility of checking the flow by heading up then; nor would a head regulator to the canal bring a remedy, as the discharge required for the basins is so large that the high velocity becomes a necessity during September. All that can be done is to make spurs and prevent the sides from eroding.

'I believe that, if the spurs had not been made, our dredging bill would have gone on increasing from year to year from the cause pointed out by Colonel Ross, and that in bad years the quantity of dredging to be done would have been beyond the power of the dredging plant available, and have required an expenditure far in excess of our allotments. Instead of which, there are indications of a permanent decrease. I scarcely like to call them more than indications at present, as the figure for 1891 was not encouraging, but there were special reasons for the high

figure of that year, and it is partly accounted for by the method of dredging downstream, under conditions most unfavourable for the employment of such a method.'

In the Report of 1896 Mr Wilson writes as follows:—

'The quantity dredged was slightly less than that of 1895 and the lowest on record. The level of the bed at the mouth was fixed at R.L. 42·30, and the bed was dredged to a slope of $\frac{1}{10,000}$ as in previous years. The reduction in the quantity is due greatly to the spurs, which have produced a narrower and more uniform channel than previously existed. But a great part of the decrease is due to the favourable conditions of the river at the offtake of the canal. There was a large sandbank upstream of the offtake, and the water arrived at the canal after having deposited a great part of its silt in forming this sandbank.'

Mr Eads' observations on the Mississippi fully bear out Mr Wilson's statement that there are two factors in the silting up of the Ibrahimia Canal, and that the amounts of the silt deposits depend as much on the condition of the river at the head of the canal as on the spurs.

The fellahin classify the basin canals as 'muddy' or 'sandy,' according as the water they carry is rich in slime or sand. They naturally prefer the muddy canals, of which the Sohagia is the arch type. Such canals, they say, take off severe curves of the Nile, and have no shoals or shifting islands near their heads. The sandy canals are of the type of the Girgawia (the worst of all) and the Ibrahimia, which take off straight reaches with shifting shoals near their heads. Village head-men have frequently informed me that they would far sooner have their lands in the fourth or fifth basin of the Sohagia, than in the first of the Ibrahimia or the Girgawia, which enjoy a very bad reputation. They propose the removal of their heads, but that is practically out of the question. The training of the Nile for 7 or 8 kilometres upstream of the heads of canals which are encumbered with shoals, might suffice to improve the canals.

From 1884 to 1891 the river was scouring out severely upstream of the Ibrahimia Canal, and the centre of scour was travelling northwards. In 1891 the scour was severest just upstream of the canal head. In 1892 it had just passed the head. In 1896, and more fully in 1897 and 1898, the scour has absolutely ceased near the canal head, and there are sand-shoals just upstream of the head. The water in the canal is not charged with excess silt, and the spurs complete what the river has done. When we come to the Rayah Menufia Canal in the Delta, it will be found that up to 1887 there was no silt deposited in this canal, as the scour was away from the canal head on the opposite bank of the river. Since 1887, however, an attempt has been made to scour away great part of the sandy island just upstream of the Barrages and directly upstream of the Rayah Menufia, and the canal has silted up very considerably, and in spite of heavy expenditure on dredging has never given the discharge it gave previous to 1887, when there was no dredging whatever. The Rayah Menufia has a slope of $\frac{1}{12,500}$, a depth of 6 metres, and a velocity in flood of about 1 metre per second."

In CHAPTER VI., paragraph 66, was given a selection from Mr E. P. W. Foster's report on the training of the Rayah Behêra through the sand-hills in its upper reaches. This was a very successful operation.

The deposits considered so far have been those chiefly due to severe velocities scouring out the sandy sides of the canals and raising the bed.

We now come to the deposits which are caused by the checking of the velocity of the water and which are far more serious. We quote from the second edition of this work :—

"To find out the velocities at which silt deposit takes place in canals taking off suitable points of the river I instituted a series of very careful experiments in four canals in Lower Egypt during 1884, 1885, and 1886, and came to the following general conclusions. In canals with their heads suitably placed :—

1. A mean velocity of from ·70 to 1·00 metre per second does not cause any appreciable deposit.

2. A mean velocity of ·60 metre per second causes a deposit of ½ a metre in an ordinary flood.

3. A mean velocity of ·50 metre per second causes a deposit of 1 metre in an ordinary flood.

4. A mean velocity of ·40 metre per second or less than ·40 per second causes mud deposits.

August and September are the chief months for silt deposition, while in October the water in the river is much less heavily charged with silt. In November and December the water is comparatively clear, and if advantage is taken of this clear water it can be utilised (and has been so utilised) to scour out the deposits of fine mud in the canals before the mud has had time to harden and consolidate. By opening all the regulators and inducing a strong current, considerable quantities of light silt can be removed from the beds, and especially the sides of the canals.

If to every ordinary canal which had its head suitably placed there could be ensured a velocity of from ·70 metre to 1 metre per second in flood time, there would be practically no silt deposit. Before this velocity could be obtained a regular flow of water from head to tail would have to be ensured. During the six years that I held charge of the Second Circle, there was no subject to which I devoted more attention than to this one of silt deposits, and I found that if a definite method were adopted and rigidly adhered to, the results were really extraordinary, while the least inattention or carelessness was attended with heavy penalties. Nor was this at all extraordinary, considering the rate at which silt can deposit if conditions are favourable. During the flood of 1885 I noticed that the left half of the Damietta Barrage was silting fast, and had daily measurements made in the second opening from the left flank. The following facts were disclosed :—

The depth of silt deposited on the			14th	August was	·50	metre.
,,	,,	,,	15th	,,	·12	,,
,,	,,	,,	19th	,,	1·30	,,
,,	,,	,,	17th	,,	1·10	,,
,,	,,	,,	18th	,,	·08	,,
,,	,,	,,	19th	,,	·50	,,
,,	,,		in 6 days .		. 3·60	metres ;

and altogether, between the 9th and 26th of the month, or in eighteen days, 6·40 metres of silt were deposited until the silt came to the water's edge.

The accompanying sketch gives the Naggar, Sabbal, and Nenaia Canals, which used to silt up in cases to the water surface of the canals in flood, and out of which the corvée cleared in 1884 as much as 900,000 cubic metres, to accomplish which some 18,000 men worked for sixty days. These heavy deposits were due to very simple causes. To ensure flush irrigation in the upper reaches of the canals the regulators 1, 2, 3, and 4 on the perennial canals in the sketch were partially closed in flood and the velocities checked. There were, moreover, no escapes for these three large canals which eventually tailed into a single canal. By constructing regulator No. 5 at the head of the Sabbal Canal, closing it

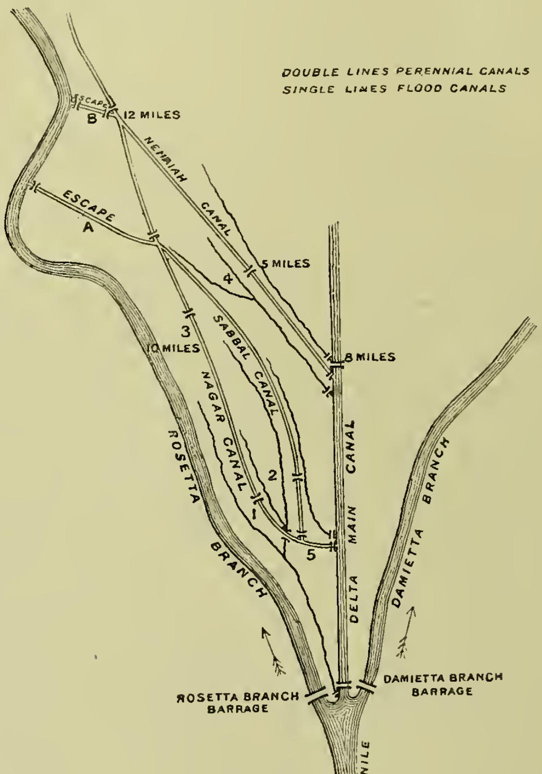


Fig. 108.

hermetically in flood, and digging the new flood canals which are shown in single lines, I was enabled to give high-level water in flood to the high lands, independently of the deep perennial canals. For these canals I provided two new escapes *A* and *B*, demolished regulator 1, and completely opened the regulators 2, 3, and 4 in flood. The result was that there was movement everywhere, and in 1887 the total quantity of silt deposited was only 30,000 cubic metres.

Among other methods employed by me with success for reducing silt deposits were: the partial closure of the heads, and complete opening of the second regulators of the very deep canals every alternate week in flood, so that a current was generated and deposits were prevented; the building of masonry regulating heads on all groups of minor canals, so that in summer water was held up to

command the highest canal and the highest canal was not silt-cleared as before to the level of the lowest; during summer, regulators were fully used, but they were kept fully open in flood when possible; and, lastly, the area irrigated on each canal was found and the supply proportioned to it, so that the favourably situated canals no longer took more than their share, and more was consequently available for the unfavourably situated canals without increasing the discharges at the heads of the main canals. Besides the great saving of labour and money in silt clearances, there were three other distinct advantages: first, the rich Nile mud, instead of being deposited into the canals, was carried on to the fields; second, all the canals had beds sufficiently low to take in water for irrigation during the winter, before the annual clearances which generally took place between February and April; third, these same canals were open to navigation carried on through the central arches of the regulators, many of which were provided with drawbridges.

We have so far considered the question of dealing with the water after it has entered the canals, and all the statements and observations have had reference to canals 'with their heads suitably placed.' We now come to the management and control of the water before it has entered the canals, so that the canal heads may find themselves suitably placed. The Nile in flood, like all silt-laden rivers, has worked out for itself a mean width and depth and slope which enables it to carry on the normal quantity of deposit which it has brought with it from its different tributaries, but this deposit is not constant in quantity or quality. In certain reaches, owing to sandbanks and shoals, it finds itself at a certain stage of the flood occupying more than its normal section, and immediately it loses some of the heavier matters carried in suspension, and it is then less heavily charged with silt than it normally is, but it is at the same time in this stage particularly capable of eating away sandy foreshores and becoming heavily charged with coarse silt. Now, if a canal takes off from a reach of the river where the river is in excellent train and is carrying its normal quantity of silt, we say that a canal head in such a reach is suitably placed. If, again, a canal head is placed in the middle of a severe curve on a dense clay reach downstream of big shoals and sandbanks where the river has left much heavy deposit and finds itself comparatively free of silt, we say that the canal head is excellently placed provided the curve is permanent. But if a canal head is placed just downstream of a sandy foreshore which the river has been attacking and from which it has been charging itself with much coarse deposit, we say the canal head is most unsuitably placed. It is on these accounts most important that canal heads should either be placed at naturally suitable places; or if the canal heads are already placed, the reaches of the river should be made suitable. All the natural canals fed by the river take off from heavy curves in stiff clay where the river is not charged with silt in an inordinate degree. Such canals are particularly free from silt deposits if carefully handled. Artificial canals, on the contrary, which have had their heads fixed without proper forethought, are singularly liable to silt deposits. The river upstream of their heads is perpetually changing its course, in one year passing the canal head lightly charged with silt and in another year laden with silt. In the years that the river is lightly laden the silt deposits in the canals are insignificant, provided the canal has not been mismanaged. In the years that the river is laden with silt, the silt deposits in the canals are heavy whether they are well or ill

managed. The Sohagia and Kasra Canals in Upper Egypt are excellent examples of well-placed natural canals. Linant Pasha, in his memoirs, speaking of the Baguria Canal in Lower Egypt, which had a very well-placed head in pre-Barrage days, states that it never silted. The Khadarawia never silted if it was carefully managed. The Ramadi, Fadilia, and Girgawia Canals in Upper Egypt, on the contrary, are examples of artificial canals badly placed which are ordinarily inundated with silt. Such canals should have the river for a good 10 kilometres upstream of them well trained and fixed on the principles just enunciated, and the silt deposits would immediately decrease. The Ibrahimia Canal in Upper Egypt is an example of a canal with its head badly placed. This canal has been most judiciously treated during the last fourteen years, but is still at the mercy of the river. For years the river kept eating away the banks just upstream of it and deluging the canal with silt. During the last two or three years a shoal has formed upstream of the canal head, the river has parted with its silt to form the shoal and passed the canal head comparatively free of silt, and the silt deposits have been quite insignificant. The Rayah Menufia at the Barrage was perfectly free of silt for years while the river passed its head comparatively free of silt. Ever since operations were undertaken to eat away the western half of the island upstream of the Barrage the canal has been deluged with silt. This rectification of the river bank was necessary in the interests of the Barrage, but the heavy silt deposits at the Rayah Menufia have represented the price which has had to be paid. This rectification will soon come to an end, and if then the Rayah head is suitably placed near the Rosetta Barrage, the silt deposits will cease.

There is yet a third class of silting up of canals. This silting up takes place in the lower and tail reaches of canals, when the discharge and velocity in flood are temporarily or permanently reduced, and the channel section accommodates itself to the new conditions. It is on this account that weekly reductions of supply or rotations in flood are to be deprecated unless all the regulators from head to tail are fully opened at the same time. With all the regulators fully open, scour can be obtained, and very recent silt deposits can be most successfully swept out of canals. But this can only be done on canals with proper escapes. On canals without escapes the lower regulators have to be shut (unless the canal head is hermetically shut), and then begins the silting up of the lower reaches so deprecated in Chapter VIII. This same silting up takes place if the discharges are permanently reduced. Suppose a canal discharging 100 cubic metres per second in flood at its tail has a regulator built on its tail reach in order to raise the water level, and has constructed from the upstream side of the regulator two minor canals or 'genabias,' capable of discharging between them 30 cubic metres per second. The tail reach of the canal will silt up to suit a discharge of 70 cubic metres per second, and unless the minor canals are made capable of discharging 30 cubic metres per second from head to tail and continued to the lake, the canal will have lost escape power represented by 30 cubic metres per second. It is this perpetual dwindling down of canals which is a serious feature of perennial irrigation as actually practised."

There are few canals in Egypt to-day which silt more than the Ramadi Canal in the south. It takes off a bad sandy foreshore, and the sand pours into the canal. If the canal head were taken a little downstream

of the sandy foreshore and then aligned backwards, there would, we think, be less silt, and the foreshore might be fixed upstream by judicious spurring. Mohammed Bey Shafîk, the Inspector of the Fifth Circle, during the discharge of the Edfu basin, seeing the level of the Nile very low, turned the escape water of the basins into the canal and made it run up the canal and into the Nile as the slopes permitted of it. This water scoured out the silt very thoroughly, and saved the State £5000 in silt clearance. Mr Langley, the Inspector-General, hoped to repeat the operation every year that the Nile was fairly low at the time of discharge.

The new Kilabia Canal head which takes off from above the Esna Barrage, was fed over a very extensive sand-shoal, generally higher than the bed of the canal, and silted very badly, as will be seen from the following report by Mohammed Bey Shafîk :—

"Periodical discharges of the Asfun and Kilabia Canals have been taken and velocities for every 0·5 metre of depth and at every 2·00 metre on the line of the cross section, with the current meter.

The result of these observations and calculations is shown in this table :—

Table 216.—Asfun Canal Silt Deposits.

(Bed-width, 12 metres; side slope, 1/1; area served, 45,390 acres; bed-level R.L., 76·00 metres.)

Date.	Water Level, R.L.	Mean Velocity. Metres per second.	Area of Section. Square metres.	Discharge. Cubic metres per second.	Depth of Silt Deposit.
August 21 .	79·72	0·95	73	69	0
25 .	80·90	1·51	98	110	0
30 .	80·90	1·09	111	121	0
September 5 .	81·04	0·82	114	93	0
8 .	81·04	0·84	113	95	0
10 .	81·02	0·81	113	92	0
11 .	81·00	0·93	110	102	0
13 .	80·90	0·75	110	82	0
20 .	80·82	0·54	105	87	0
26 .	80·70	0·53	101	84	0
30 .	80·75	0·61	102	62	0
October 5 .	80·55	0·51	98	50	0

[Table

TABLE 217.—KILABIA CANAL SILT DEPOSITS.
(Bed-width, 14 metres; side slope, 2/1; bed-level R.L., 76·50 metres; area served, 26,200 acres.)

Date.	Water Level R.L.	Mean Velocity. Metres per second.	Area of Section. Square metres.	Discharge. Cubic metres per second.	Depth of Silt Deposit.
August 15 .	77·80	0·40	20	8	0
20 .	79·12	0·63	48	30	0
26 .	80·80	1·04	92	96	0·5
30 .	80·86	1·26	72	91	3·3
September 5 .	81·00	1·27	77	97	1·7
10 .	80·98	1·34	58	78	2·1
15 .	80·94	1·34	56	75	2·1
20 .	80·80	1·37	53	74	2·2
26 .	80·70	0·84	76	64	0·9
30 .	80·66	0·88	77	68	0·6
October 5 .	80·48	1·05	51	54	1·8

It is evident that it is not the low velocity that causes silt, but the high one. The Kilabia table shows that the higher the velocity the greater the silt.

The phenomenon is explained thus :—

Under a moderate velocity no sand can be transported from the sandy island upstream of the Kilabia head; but when the velocity is increased, this sand is rolled and rapidly deposited on the Kilabia bed.

To stop this sand from being swept from the island into the Canal, a channel

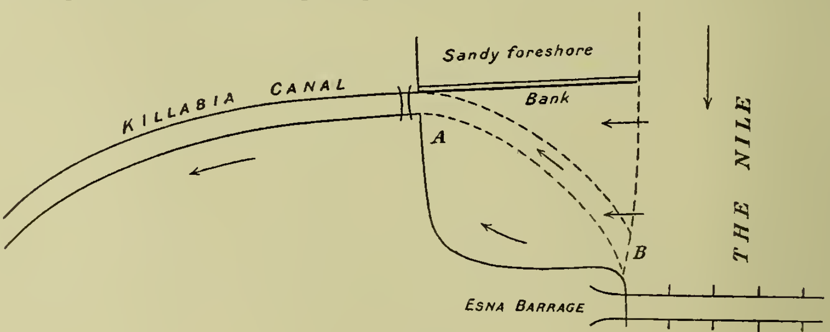


FIG. 109.

with a bank higher than the water level will be made during the summer of 1912 to feed the Canal from a point at which no sand exists in the river bed.

Asfun and Kilabia are examples of good and badly placed canal heads. The velocities, sections, and discharges shown in the above tables for the two canals are similar, but the silt deposited is widely different, owing to the fact that at the take-off of the Asfun Canal no sand island exists."

Since the above was written, Shafîk Bey tells us that Mr Langley ordered a stout earthen bank above high-flood level, well pitched with stone, to be taken out into deep water as in fig. 109.

When we saw the canal after the flood, there had been no silt deposit to

speak of. We think that if the canal was dug along the line B A, it would be just like all the canals designed for Mesopotamia, and silt might permanently cease downstream of the regulator. If there were any silt, it could be stopped by some judicious spurring on the Nile upstream of the head.

The silt question has been deeply studied in the Punjab, where the deposits in the Sirhind Canal were at one time so serious that they threatened to obliterate the canal. The deposits were reduced out of recognition by two modifications of the original design. The first was the construction of a river-wall some 70 * metres long from the right flank of the under-sluices parallel to the axis of the river and the canal head face, enclosing a silt trap A B. The next was the raising of the floor of the regulator from 0·60 metre to 2·75 by a sill. The water of the river laden

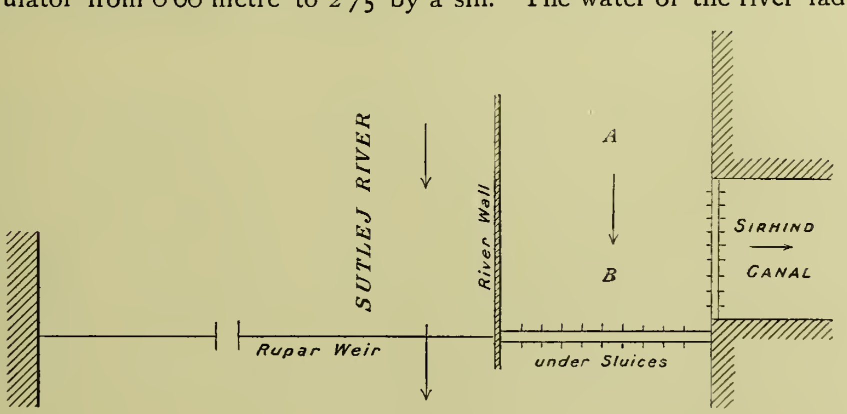


FIG. 110.

with silt has to pass through the trap before it can enter the canal. By opening the under-sluices periodically, all the coarse silt which has deposited is swept away and the trap made ready for trapping more silt. Meanwhile the gates of the canal head are housed behind the raised sill and raised when desired so that water always enters the canal from near the surface of the river free of coarse silt. The results have been very satisfactory. There are modifications of these principles, as may be seen in CHAPTER VII. of Bligh's *Practical Design of Irrigation Works*, or CHAPTER IX. of Sir Hanbury Brown's *Irrigation*, but the principles themselves are sound.

The ideal velocity in a channel which will prevent silt deposit has been studied on one of the Punjab canals by Mr R. G. Kennedy, and his observations have been printed in *Graphic Hydraulic Diagrams* and in *Proc. Inst. C.E.*, vol. cxix. p. 281. They are also given in Buckley's *Irrigation Pocket-book*, pp. 117–119. They depend on the fineness of the silt carried. His general conclusions are that canals with high velocities should be deep and narrow and with low velocities wide and shallow for the same discharge. In Egypt this question has not been studied.

* This dimension may be wrong, but it does not affect the principle.

CHAPTER X.

ENGINEERING DETAILS.

111. **The Older Regulators.**—Masonry works for regulating the supplies in canals at their heads or at any part of their course, and similar works in the banks of the basins for regulating the supplies from one basin to the other or for escaping the water from the basins into the Nile, all come under this category. Nearly all the works have their floors flush with the beds of the canals. This necessarily follows from the fact that the perennial canals often carry in summer a much smaller supply than they carry in flood, while the flood canals have the same vicissitudes between a year of high flood and a year of drought.

The following table (Table 218) gives details of some typical old Egyptian regulators.

The old regulating heads of the canals used to be retired from 100 to 300 metres from the edge of the Nile. This meant heavy silt clearances upstream of the heads if the regulators were much used in flood, but it ensured the construction of the work on fairly good soil. Recent practice has consisted in taking the head regulators well forward and protecting them with pitching. Newly formed foreshores should, however, be avoided, as they consist at times of a most unreliable soil. The abandoned upper head of the Ismailia Canal and the Bahr Saidi head in Gharbia are examples of works taken too far forward and constructed on a soil with but little consistency.

In regulating works we often see designs in which the floor has up- and downstream curtains taken a metre or so below the general level of the floor. If the soil is stiff clay or dry sand, where the foundations can be got in without pumping, the curtains are well placed. If, however, the foundation is on sand or silt below spring level, and pumping is required to put in the curtains in the dry and the spring level is temporarily lowered below the general foundation level, the superstructure may have unsightly cracks when the works are completed and put to use. In such cases the

TABLE 218.—DETAILS OF OLD EGYPTIAN REGULATORS (in metres).

Name of Regulator.	No. of Openings.	Width of Openings. Central.	Width of Openings. Side.	Maximum Depth of Water on Floor.	Maximum Head of Water.	Thickness of Floor.	Height of Wing Walls.	Height of Roadway above Floor.	Length of Floor.	Length of Arch.	Length of Floor Upstream of Arch.	Length of Floor Downstream of Arch.	Thickness of Wing Wall at Top.	Length of Downstream Wing Wall Return.
Nashart	5	3·68	3·00	6·00	3·50	2·50	7·15	9·10	34·50	7·80	5·40	21·30	2·20	19·50
Rahbain . . .	9	5·10	2·20	7·80	2·50	3·00	8·10	11·00	36·20	12·70	4·60	18·90	1·50	17·50
Tanta	2	3·20	3·20	4·80	3·00	2·00	5·00	7·40	22·40	5·60	9·40	9·20	1·20	11·20
Ganzur	3	3·50	2·50	6·50	2·50	1·70	8·00	11·00	34·80	9·80	5·70	19·35	2·00	11·00
Birshams South . .	3	4·50	2·40	9·0	2·50	1·50	8·60	11·00	24·10	9·00	5·40	9·70	2·30	11·00
Baguria	5	4·00	3·00	8·0	3·00	(?)	8·10	10·20	32·10	9·30	4·00	18·80 (broken)	1·75	10·70
Shubrabas . . .	5	4·00	3·00	7·0	3·0	(?)	5·70	8·20	20·70	6·70	5·00	9·00	3·10	7·35
Birshams North .	7	5·50	2·10	9·0	3·0	(?)	8·30	12·00	32·80	10·80	4·80	17·20	2·35	11·90
Nenaia Head . . .	2	3·00	3·00	7·5	3·0	1·80	7·80	10·80	33·80	9·21	6·00	18·60	2·00	11·80
Khadarawia . . .	3	3·10	2·35	9·0	3·0	2·0	7·50	9·70	24·40	7·90	2·60	14·00	1·60	10·90
Basiun	8	3·00	3·0	6·0	2·0	2·2	6·4	8·4	36·5	5·5	8·0	23·0	1·80	6·00
Nenaia Reg. . . .	10	4·0	4·0	8·0	1·0	2·0	7·95	11·05	36·5	6·8	10·45	19·25	2·0	15·60
Karanain . . .	10	5·0	5·0	9·0	3·0	3·0	8·6	10·28	34·7	6·0	7·4	20·5	1·0	19·00
Santa	11	5·16	2·28	9·0	3·0	2·0	8·5	11·50	40·25	6·85	12·40	21·00	1·20	
Demera	7	4·67	2·08	8·0	3·0	2·0	7·25	10·00	37·00	5·00	11·00	21·00	1·70	

curtains should be excavated with the water standing in them and formed of cement concrete tipped into the water. It is better, however, to have recourse to iron piles. Whatever is done, the pumping should on no account be taken below the general foundation level. During the repairs of a massive regulator in Egypt which had a deep pool scoured out downstream of its floor, the unwatering was by an oversight continued until the level of the water in the pool fell below the foundation level, and the whole regulator slid into the pool and became a complete wreck. Infinite damage is occasionally done to works whose floors are carelessly laid dry during the repairing season. Pumping on such occasions should be undertaken with the utmost caution. How often has a serious crack been seen to extend down the whole length of a lock floor when the weight of the water has been suddenly taken off the floor and the original design has not provided for wells or extra support of some kind for the heavy lock walls! A perfect work built on sand saturated with water, in India, provides for wells descending below the general foundation level under the abutments, the piers, and especially the lock walls. Where works designed with proper well foundations have not proved a success, it has generally been due to pumping carried down to excessively low levels to expedite well sinking—an operation which has deranged the soil below the general foundation level. In Egypt, however, we prefer massive floors enclosed by piles, as our sand is too light for wells to be sunk successfully.

The question of the best form of foundation for a regulating work on sand is one of the very greatest importance. Opinions are by no means uniform on the subject, but certain principles are accepted by those most competent to form an opinion. A head of 4 metres of water is the maximum which should be placed on any work built on sand or silt. A mass of loose stone pitching traversed longitudinally by insignificant masonry walls, as at the Okhla dam (on Plate LV.), is quite capable of holding up to 3 metres of water, and becomes staunched by the mud held in suspension during flood, provided the submerged weight of the mass of loose stone bears to the water pressure a proportion of 40 or 50 to 1. In regulating works which have masonry floors, it is better to extend the floor on the upstream side of the line of regulating gates than to extend it considerably on the downstream side after a distance of from 10 to 20 metres, depending on the importance of the work. On the downstream side there should be provided an apron of loose pitching which the water cannot displace, and which can give a vent to clean springs throwing water which contains no deposit. Staunching this downstream pitching with mortar and making it water-tight can only be compared to the act of making the downstream slope of an earthen dam water-tight. Make the upstream side as water-tight as possible and have the downstream talus permeable.

The *system of regulation* in ordinary use in Egypt before 1885 was that

of *vertical needles*, resting against horizontal girders or beams; the horizontals were fixed to a frame, which moved in the grooves. The accompanying sketch shows the four vertical timbers (generally 25 centi-

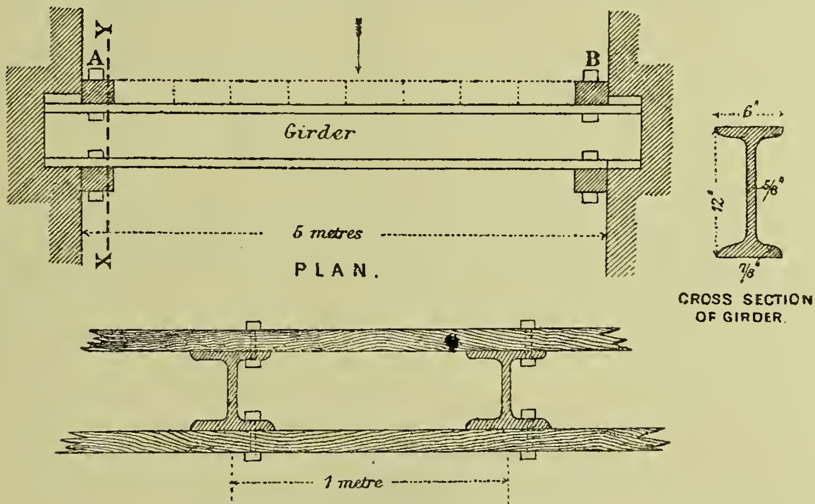


FIG. 111.

metres × 15 centimetres in section), to which were bolted the iron horizontals. The vertical needles were lowered between A and B, and rested against the girders. There were two great advantages in this system :—

1. The vertical needles divided the falling water into a number of threads, and so completely broke its force. They thus protected the floor and the pitching, and did away with the necessity for cisterns or solid stone floors. An ordinary brick floor, without any cistern, easily stood the shock of from 10 to 15 cubic metres of water per second per metre run of floor falling 2 metres, provided the verticals were carefully spaced, and driven down to the floor.

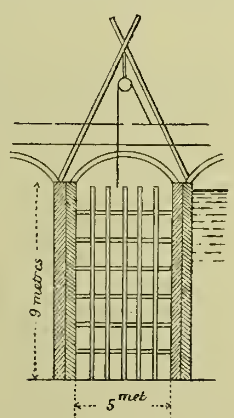


FIG. 112.

2. This system could be used in any depth of water. It answered as well in 9 metres of water as in 3 metres. A pair of sheer-legs was erected over the opening, and the verticals were lifted by a 3½-inch rope, working over pulley-blocks, and lowered in front of the horizontals; the water drove the verticals against the horizontal frame. When a sufficient number of verticals had been thus lowered, a wooden monkey was attached to the rope passing through the upper pulley-block, and the verticals driven home, and then spaced. For lifting the verticals, if the head of water was over 1 metre, the most ready method was to attach a chain to the head of the vertical tie, the other end of the chain to a loose timber lying on the bridge, and, making use of the parapet as a fulcrum, raise the vertical by leverage. The final operation of lifting the vertical out of the water and laying it on the bridge was performed by the sheer-legs. This was the system of regulation practised in Egypt

from time immemorial. Either iron girders or oak beams were used for horizontals. For the verticals, pine-wood (Kamera) was preferred to fir (Bartum). The upstream parapet of the bridge had two wooden beams running along the edges (as at A and B, in section), to protect the parapet from the rough handling it received. Where stone was cheap a course of ashlar replaced the wooden beams. The needles used in Egypt had originally far too large a section, and were in consequence unwieldy. For depths of 5 metres and under, a section of 10 centimetres × 10 centimetres was found to suffice. The disadvantages of this system were:—

1st. The necessity of having a large gang of men to work the needles; and

2nd. The difficulty of making a water-tight closure.

The first disadvantage was not felt during the flood, since there were always corvée labourers available; nor was the second of much consequence in flood, since no water-tight joints were really needed at that time of the year. In summer, however, no corvée was latterly available for this kind of work, while water-tight closures were frequently needed, and consequently some change became necessary.

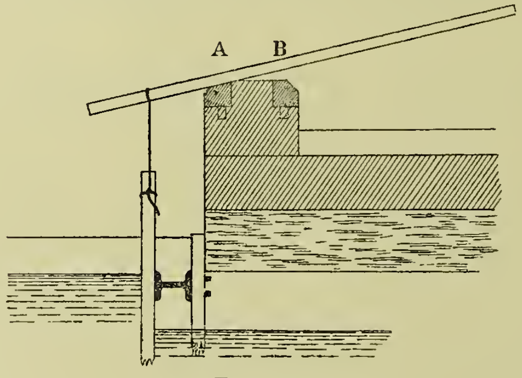


FIG. 113.

Advantage was in places taken of the fact that nine out of ten of the regulators had their floors much lower than was necessary to raise the floors to the highest level possible with efficiency by means of masonry walls. The regulation by means of vertical needles was carried on above them. The water was broken up into threads as before, while the length of the needles was reduced by 2 or 3 metres.

Since 1886 for depths of water of 5 metres and under, movable horizontal sleepers have been introduced and gradually have displaced the needles. They make a water-tight joint and need a much smaller establishment. They are manipulated with a head of water of as much as 3 metres. Of course the main difficulty lies in lowering the sleepers through so great a depth of water and against so great a head, and this is often not successfully accomplished. Lowering and raising the horizontal sleepers is performed very much as it is on the canals in Upper India, where the depth of water never exceeds 3 metres. Where the regulators are of any magnitude the horizontal sleepers are raised and lowered by means of a carriage travelling on rails, of which the drawings in figs. 114 and 115 taken from M. Barois' *l'Irrigation en Égypte*, give a very good idea.

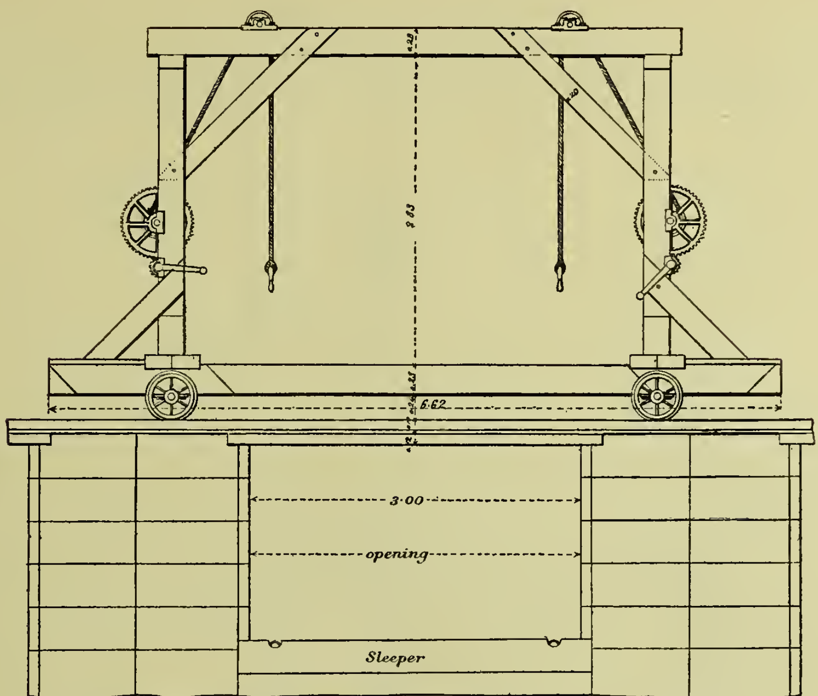


FIG. 114.—Travelling Carriage for Horizontal Sleepers. Front Elevation.

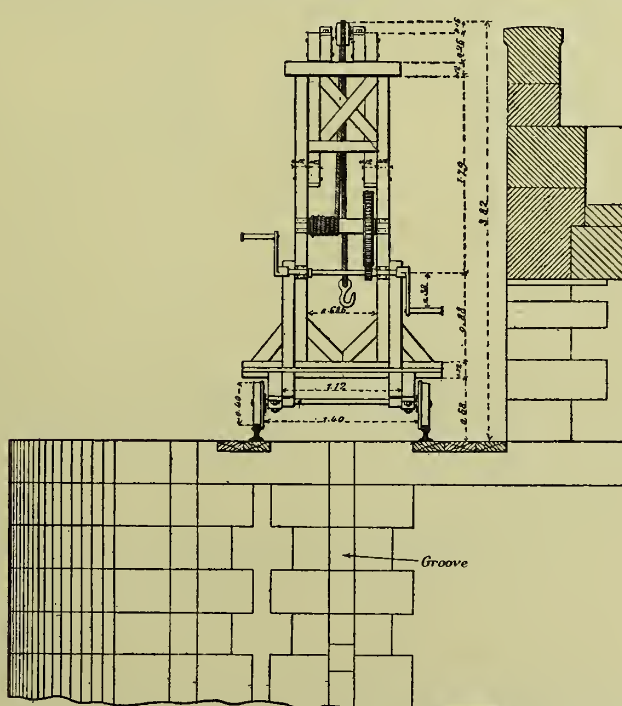


FIG. 115.—Travelling Carriage for Horizontal Sleepers. Side Elevation and Section

For the regulators on the Rayah Tewfiki, Colonel Western and Mr Reid constructed wrought-iron gates, worked by travelling crabs. Figs. 116

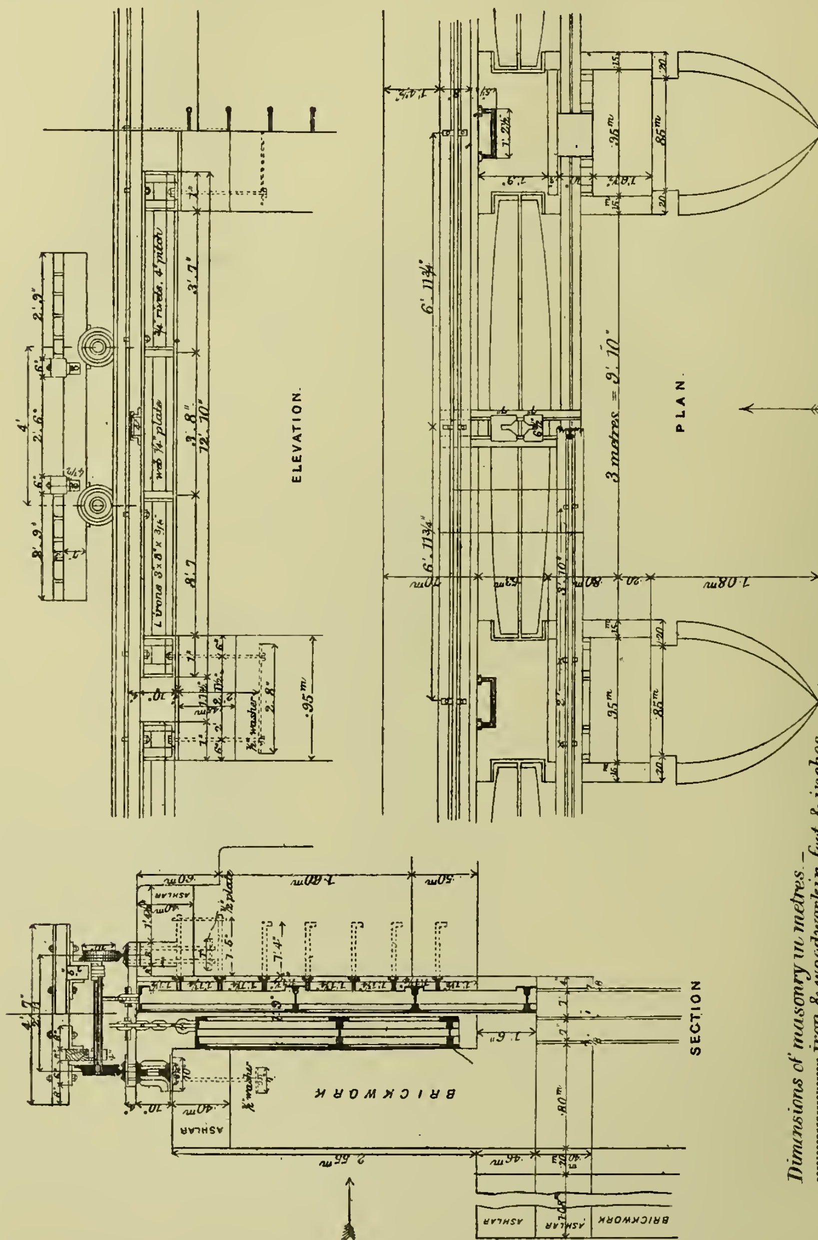


FIG. 116.—Gangara Regulator. Regulating Apparatus (1). Approx. Scale $\frac{1}{60}$.

and 117 give details of one of these gates. Each opening is provided with two gates, sliding in separate iron grooves, which together form a double groove. These gates are easily worked, and can make a water-tight joint;

the openings are 3 metres wide in every case. At the Barrage, where the openings are 5 metres wide, the gates are provided with two rollers on each

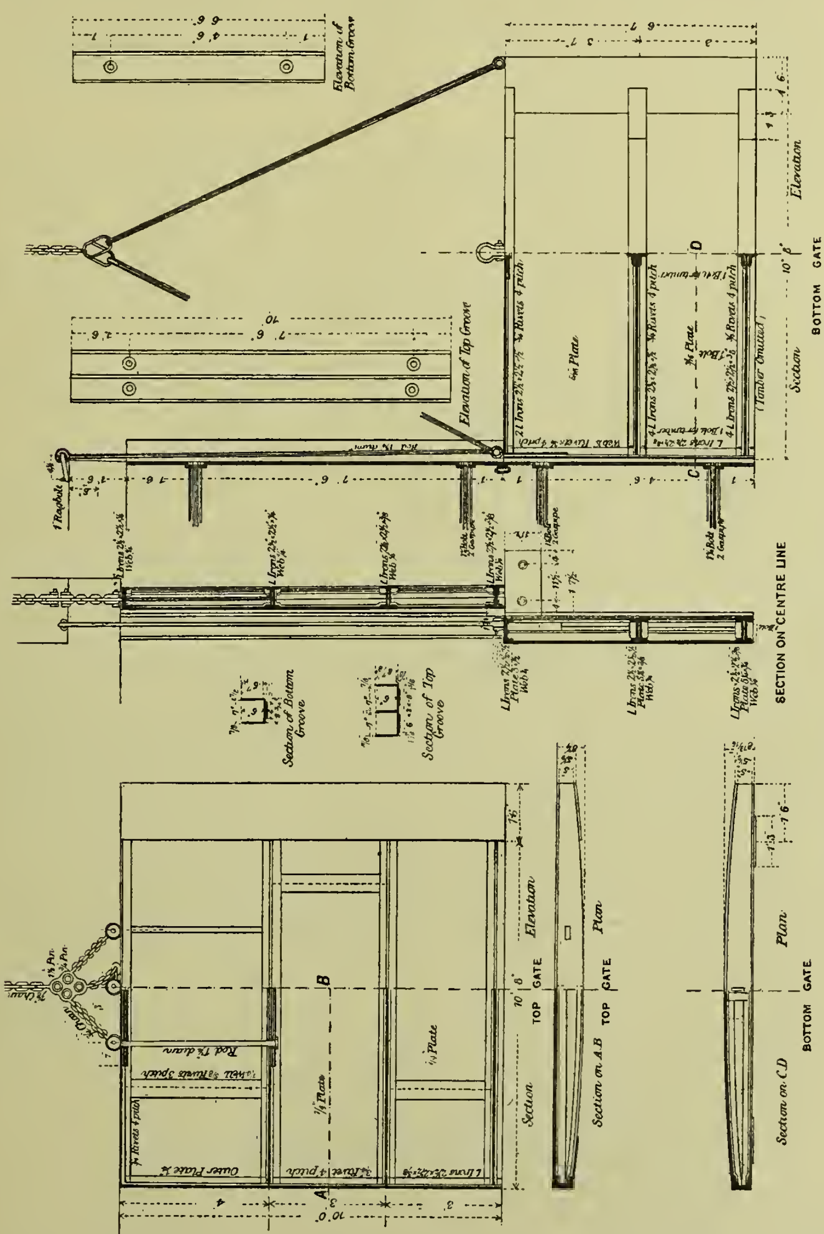


FIG. 117.—Gangara Regulator. Regulating Apparatus (2). Approx. Scale $\frac{1}{60}$.

side, in order to lessen the friction between the gate and the iron groove. The gates descend by their own weight.

In order to give good examples of Egyptian practice in the design

of regulators, we give details of regulators constructed since the Occupation.

"*Gangara Regulator on the Rayah Tewfiki Canal* (*Egypt*).—The Gangara regulator, designed and built by Colonel Western and Mr Reid, is the first ordinary regulator on the Rayah Tewfiki, and consists of a regulator and lock combined. The lock is 50 metres × 8 metres.

The regulator has 6 openings of 3 metres width each, with piers 1·40 metres wide.

The maximum depth of water is 6·30 metres and the maximum head 3·0 metres. It is built on good stiff clay.

The width of the floor is 16 metres, and the depth 1·75 metres. The piers are 11 metres long and 6 metres high, and support a roadway on their downstream side. On the upstream side they support towers ·80 metre × 1·40 metre and 2·25 metres high, which carry a girder, while the upstream parapet of the bridge is raised to the same level as the girder. The upstream parapet and the towers carry a line of railway on which moves the travelling crab which works the gates. When not needed for regulation, the gates are housed between the towers and the upstream parapet.

The grooves are double and of cast iron.

The regulation of each opening is performed by two wrought-iron gates moving in the grooves. The lower gate is 1·00 metre high, and the upper gate 3·00 metres high. The gates are made of wrought iron with the ordinary arrangement of girder and sheeting on one side. The lower gate is lowered and raised by means of suspension rods which rest in the grooves when the gate is down. The upper gate is raised and lowered by means of chains. The traveller is an ordinary winch on a carriage.

This regulator cost £16,867, and began working in 1889. The amount of ironwork in each opening is—wrought iron 18,000 kilograms and cast iron 9000 kilograms. The gates and overhead platform of each opening cost £825. The cost per running metre of floor is £42. The cost of regulating apparatus per running metre of floor is £34. The regulating apparatus cost £8·25 per square metre of sluice gate."

"*Rayah Tewfiki Canal Head Regulator.*—The Tewfiki Canal * takes off the right bank of the Damietta branch of the Nile from above the Damietta Barrage. This canal was constructed for the purpose of connecting all the northern canals of the Eastern Delta with the canal system taking off from above the Delta Barrages. Designed by Lieutenant-Colonel Western in 1887, it was constructed in 1887–89 by Mr A. Reid, with Mr J. Langley as resident engineer. The area to be irrigated in summer was 400,000 acres, and in flood 800,000 acres, and, consequently, a discharge of 100 cubic metres per second in summer, and 200 cubic metres per second in flood, had to be allowed for. The canal has a bed width of 26 metres, depth of water of 6 metres, and a slope of $\frac{1}{12,500}$, does not silt, and is one of the most satisfactory in Egypt. The works cost as follows:—

Excavation of earthwork	£206,000
Land	23,000
Regulating head	52,000
Cross syphons	11,000
Regulators and bridges	52,000
Railway bridges	17,000
Total	£361,000

* We quote from a series of articles written by Sir William Willcocks for *Public Works*.

The regulating head is built on a very light sand, extraordinarily full of springs. Figs. 118 and 119 give a plan of the canal head, and a longitudinal section of the work. The regulator consists of six openings of 5 metres each, with piers 2 metres wide. On the left hand is a lock 50 metres by 8·50 metres. The maximum depth

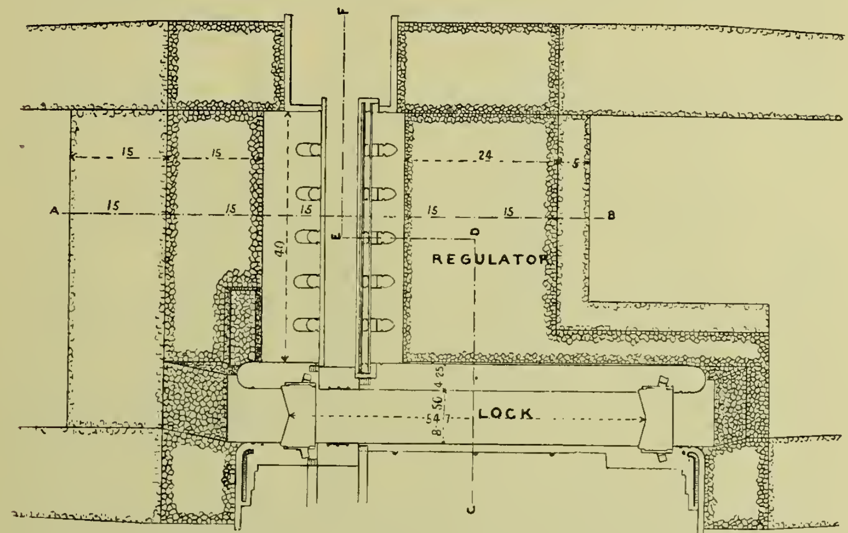


FIG. 118.—Tewfiki Canal Head. Plan. Approx. Scale $\frac{1}{1125}$.

of water is 9·50 metres on the upstream side and 6·00 on the downstream side. The maximum head is 4·00 metres.

The thickness of the floor is 2·50 metres, while the piers, abutments, and lock walls are founded on circular wells which go down to a depth of 6 metres below the level of the top of the floor. The up- and downstream curtains consist of rows

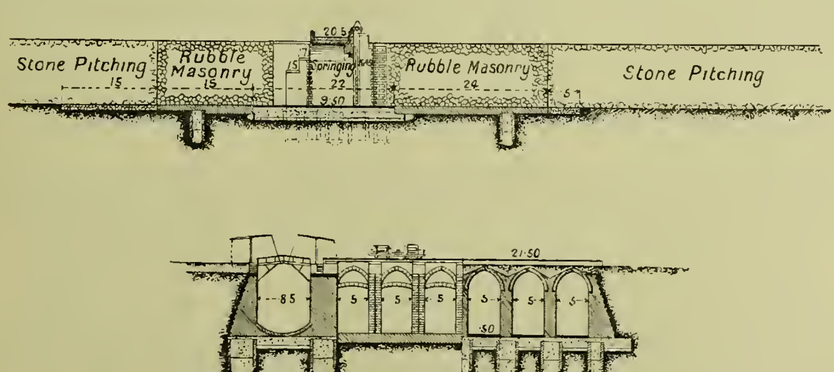


FIG. 119.—Tewfiki Canal Head. Cross and Longitudinal Sections. Approx. Scale $\frac{1}{1125}$.

of rectangular wells which descend to a depth of 6 metres below the level of the floor. These latter wells are 30 centimetres apart, each from each, and the spaces between are piled off and filled with quick-setting cement concrete after the Indian fashion. The wells were sunk by Bull's dredgers, but the absence of skilled Indian

labour was a drawback. The exact positions of the tops of the wells as they finally settled are depicted in fig. 120.*

Below the main arches it will be noticed that there are blind arches 1·50 metres wide. Each sluice opening is 7·50 metres high and 5·0 metres wide in the clear.

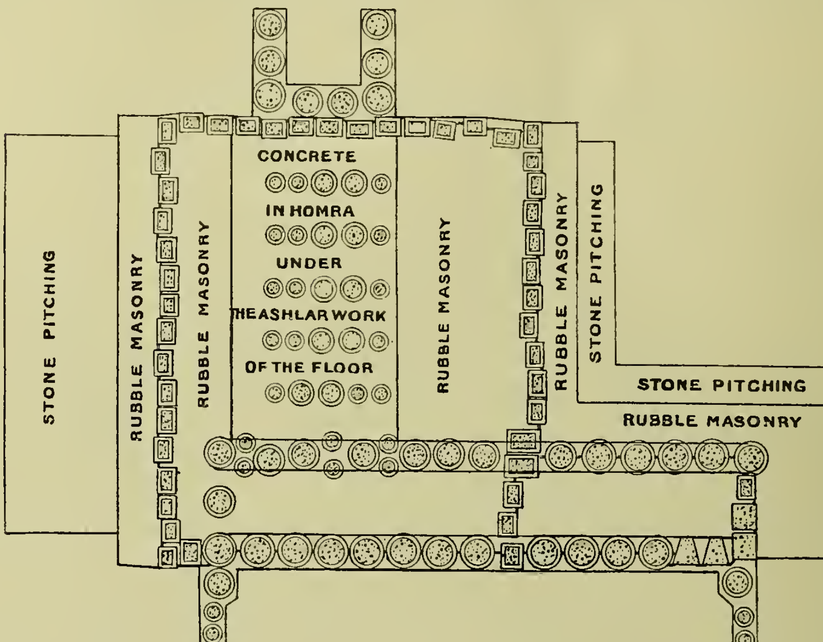


FIG. 120.—Rayah Tewfiki Head. Plan of Wells. Approx. Scale $\frac{1}{900}$.

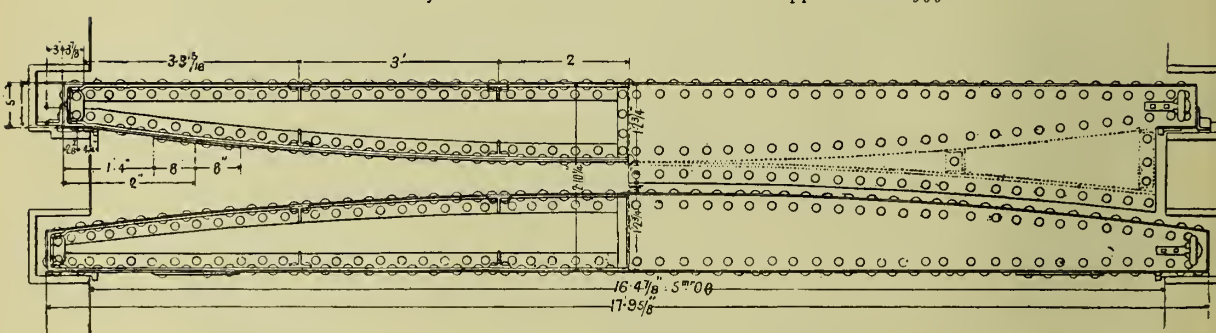


FIG. 121.—Tewfiki Canal Head Regulating Gates. Horizontal Section and Plan. Approx. Scale $\frac{1}{33}$. Dimensions in feet and inches.

It will also be noticed that the grooves both go down to the floor. They are spaced 30 centimetres apart and have let in between them horizontal I-girders buried in the masonry. By thus keeping the grooves apart it is assured that the lower gates will never have to rest against tongues of iron, but against solid resistful supports.

The regulation is performed by two wrought-iron gates the construction of which is shown in figs. 121 to 125. The method of operation is the same as that at

* The foundations of this work should be cement grouted under pressure as has already been done at the Barrage.

the Delta Barrages, except that both gates go down to the floor. In the summer the canal head is open, and the rising flood finds all the gates well above the reach

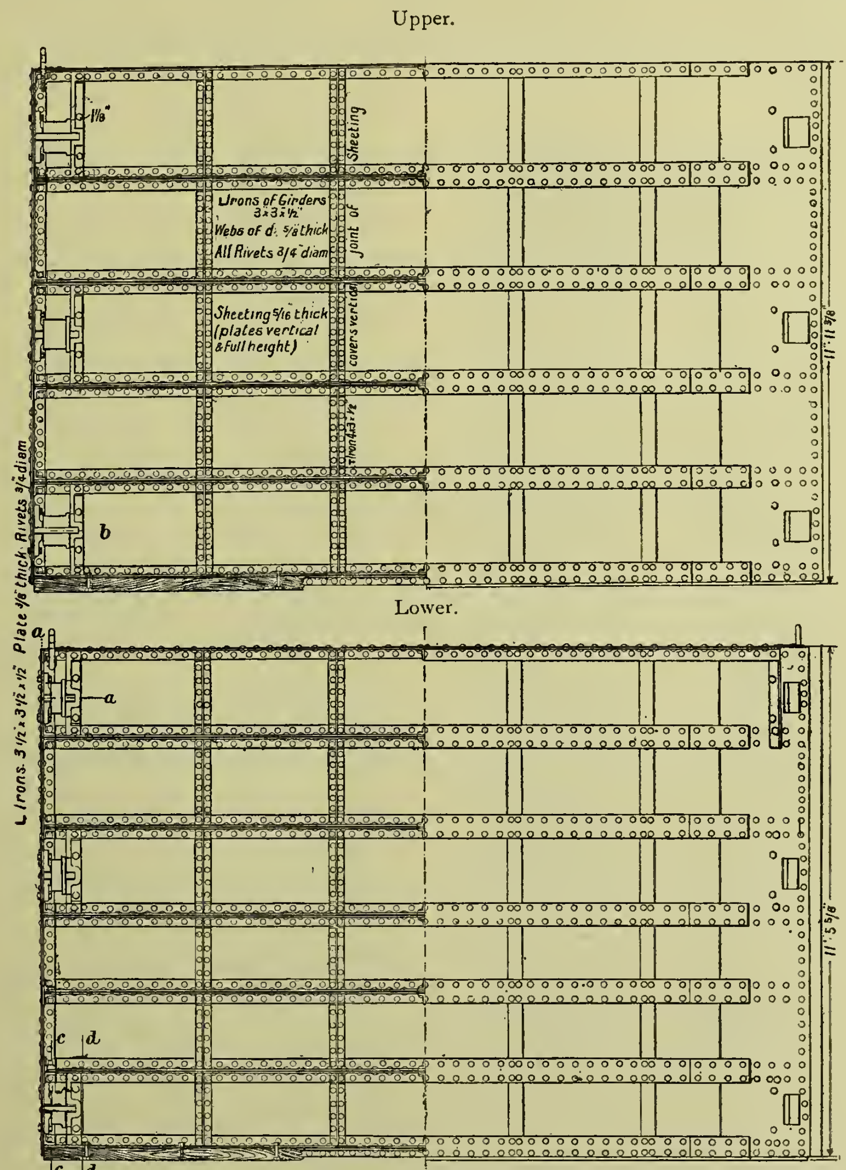


FIG. 122.—Tewfiki Canal Head Regulating Gates. Elevation and Section. Approx. Scale $\frac{1}{50}$. Dimensions in feet and inches.

of the water. As soon as the depth of water in the canal is equal to the requirements, and the flood keeps rising, both gates are lowered simultaneously until they reach the floor, and the water passes over both of them. On the Nile still rising and necessitating the further closing of the opening, the downstream gate is raised,

and regulation performed by it. The lower gate remains on the floor until the final opening on the fall of the flood. This method of regulation keeps the bottom sand-laden water of high floods from entering the canal, and has everything to recommend it. It has been found in the low unsatisfactory floods of recent years that 3·50 metres is too high for a single gate, and that it blocks up too much of an

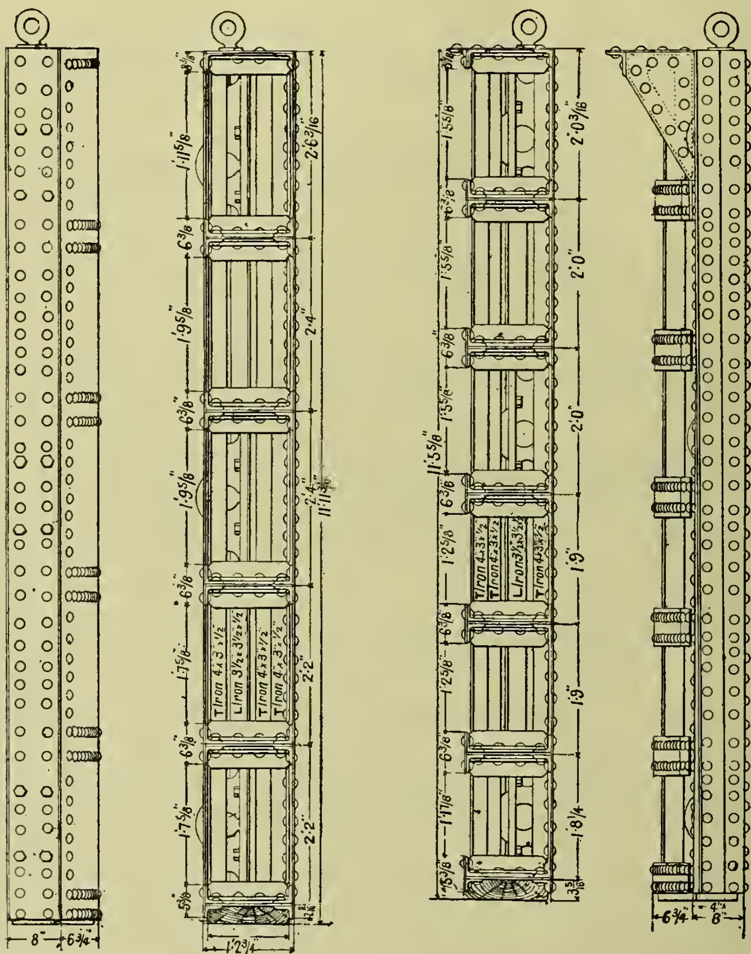


FIG. 123.—Tewfiki Canal Head Regulating Gates. Cross Section of Top and Bottom Gates. Approx. Scale $\frac{1}{30}$. Dimensions in feet and inches.

opening. The 3·50-metre gates might be reduced to 3·00 metres each, and the blind arches might be lowered by 1 metre. This would be more suitable for the canal. At the new head of the Ismailia Canal three grooves and three gates have been constructed. If the action on the floor is considered, or the fact that the bottom silt is to be kept out of the canal, it is very important to have the water entering the canal passing over the tops of the gates, and not under them. Especially is this the case in high floods.

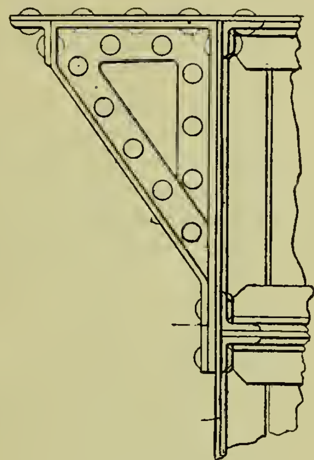


Fig. 124.—Tewfiki Canal Head. Enlarged Detail of Regulating Gates.

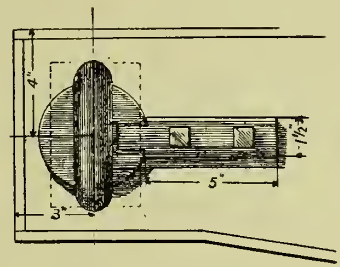


Fig. 125.—Tewfiki Canal Head. Enlarged Detail of Regulating Gates. Dimensions in inches.

The completed work was built for £51,664, thus made up :—

Earthwork,	150,000 cubic metres at		£·03		£4,500
Concrete,	7,263	,, ,,	1·00		7,263
Brickwork,	11,148	,, ,,	1·10		12,263
Rubble masonry,	4,101	,, ,,	1·0		4,101
Ashlar,	1,180	,, ,,	3·0		3,540
Metalling,	233	,, ,,	·20		46
Rubble pitching,	2,751	,, ,,	·50		1,376
Pumping					2,500
Closing springs					250
Temporary earthen dams					476
Well sinking and foundation labour					10,650
Lock gates—					
Wrought iron, 51 tons at £20				£1,020	
Cast iron, 23 ,, 15				345	
Timber £180, and opening gear £248				428	
					1,793
Lift-bridge					330
Regulating gates—					
Wrought iron, 58 tons at £20				£1,160	
Cast iron, 5 ,, 15				75	
Timber, 18 cubic metres				540	
					1,775
Travelling winch					600
Tree planting and dressing roads					201
Total					£51,664

The ironwork of the Delta Barrages, the Tewfiki Canal head, and the other regulators on the Tewfiki Canal, designed by Lieutenant-Colonel Western and

Mr A. Reid, has been taken as a pattern for the regulating gates of the Assiut weir, and for all the regulating gates made in Egypt since 1888. When necessity arises, the safety grooves are utilised by lowering frames and verticals."

"*Koshesha Escape Regulator* (*Egypt*).—The regulator, designed by Colonel Western and Mr Reid and constructed by Mr Hewat, is built on the tail escape of the series of basins from Assiut to Wasta. It consists of 60 openings, each 3 metres wide. The piers are 1·30 metres wide. See Plate XXXVIII.

The regulator is founded on good clay soil. The maximum depth of water on the floor was expected to be 6·50 metres, though it rose to 7·00 metres in 1892. The maximum head of water will be 4·00 metres.

The main floor is of masonry 13 metres wide and 2·75 metres deep; the bottom of the foundation is below the minimum summer water-level of the Nile. The upstream apron is of masonry 10 metres wide and 1·0 metre deep. The downstream apron is of masonry 12 metres wide and 2 metres deep. Below the downstream apron is 10 metres width of masonry blocks 1 metre deep, and below that again 20 metres in width of rubble pitching.

The piers are 12·5 metres long and 6·5 metres high and support a roadway on

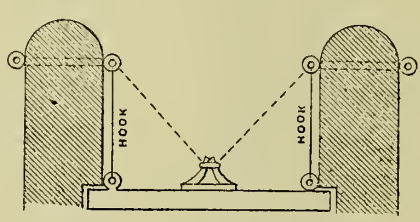


FIG. 126.

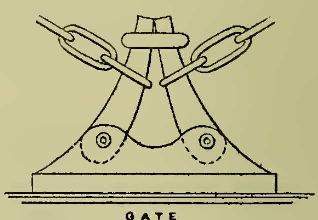


FIG. 127.

their downstream side. On the upstream side they support two towers, each ·80 metre long, 1·30 metres wide, and 1·0 metre high.

The depth of each opening is divided into two sluices by an arch thrown between the piers.

The lower sluice is 2 metres high, and the upper 3·5 metres high.

The lower sluice is closed by a vertical gate moving in vertical grooves in the piers.

The upper sluice is closed by a drop gate hinged at its bottom to its floor and falling flat on the floor when open. Both gates are of wrought iron.

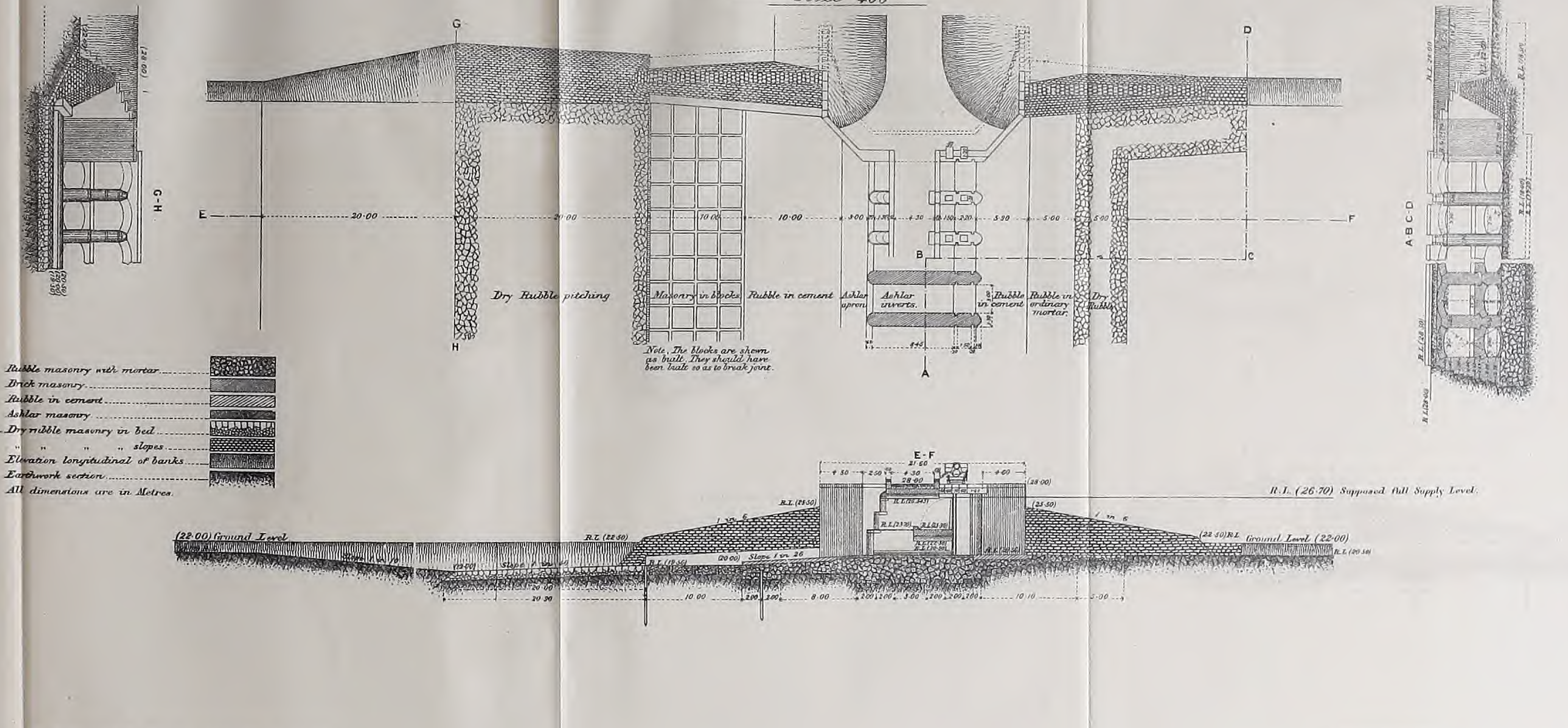
The two rows of towers carry girders and a line of railway on which travels the winch which raises and lowers the lower sluice gates in flood when the regulator is being worked. The winch is also employed to raise the upper drop into its vertical position after the flood is over and the regulator is in the dry.*

The upper drop gates are kept in a vertical position (fig. 126) by hooks suspended from bolts fixed in the piers and dropping into eye bolts in the gates near the piers, and (fig. 127) by chains attached to the same bolts in the piers and clipped by a clip at the middle of the gate. When the gate is up and under water-pressure, the hooks take the strain; when the time for opening has come, the hooks are detached and the clip links are struck off and the gates fall instantly.

* There are in reality two winches in order to expedite the opening of the sluices.

DESIGN OF THE KOSHESHAH ESCAPE OF 60 OPENINGS OF 3 METRES EACH.

Scale $\frac{1}{400}$



To face p. 578. Willcocks and Craig Egyptian Irrigation.

The regulator has worked through the flood of 1891 and 1892 and has given satisfaction. It cost £62,620.

The amount of iron work in sixty openings was :—

Cast iron	205,800 kilograms
Wrought iron	367,500 ,,
	573,300 ,,

The gates and overhead platform of each opening cost £223·5.

The cost of floor per running metre was £90.

The cost of regulating apparatus per running metre was £74·5.

The regulating apparatus cost £14 per square metre of sluice gates."

As the Koshesha escape is the most important masonry work constructed in the basins in Upper Egypt, we supplement the above information from Major Brown's paper on this work in vol. xviii. of the *R.E. Professional Papers.* After describing the work, Major (now Sir Hanbury) Brown quotes from Colonel Western's original report on the work. Here follow Colonel Western's calculations :—

"From a study of the dates of cutting Koshesha in former years we may assume, for purposes of calculation, that the basin escape will be opened on 22nd October, or nineteen days before 10th November, the date laid down for the completion of the discharge.

From a comparison of levels it is found that the heads, at the time of opening, will vary from 0·30 to 4·50 metres, and with these heads, less the rise of the river consequent on the discharge, the escape must be designed to pass 100 and 150 million cubic metres per day.

It may be remarked that in order to give an *average* discharge per day of 100 and 150 millions, the first discharge must be increased by one-half, or to 150 and 225 millions; but, considering that the basins have never to date been all full at the same time, and as the cost of the work has been limited to £60,000 or thereabouts, it will be sufficient to calculate for the average discharge for the first outflow, and then arrange, as far as possible, for the maintenance of these same discharges.

Minimum spring level at site of work may be taken as at R.L. 19·00, and foundation line must be below this, or, say, at R.L. 18·50. Floor line may then be placed at 20·50 or above. Assuming this level of 20·50, basin level at 26·70, and river at its minimum 22·20, it will be manifestly injudicious to allow, on first opening, the full depth for discharge of $26{\cdot}70 - 20{\cdot}50 = 6{\cdot}20$ metres into a backwater of only $22{\cdot}20 - 20{\cdot}50 = 1{\cdot}70$ metre + rise of river, say, $1{\cdot}00 = 2{\cdot}70$ metres.

The depth of opening must then be divided into two; the first, or upper series, to be opened to discharge the volumes demanded, 100 and 150 millions; and the lower series to be kept as a reserve, and opened only to maintain the discharge as the head decreases, or water surfaces in basin and river fall.

These lower sluices will also be available for filling the Koshesha basin during the rise of the river, the volume to be passed in being estimated at 400 million cubic metres.

From various trial calculations the upper sluice-gate has been fixed at 3

metres in depth, or from R.L. 26·70 to R.L. 23·70. Assuming this depth, and the formula for discharge in cubic metres per second, discharge

$$= \tfrac{2}{3} l \times 4{\cdot}43 \sqrt{h} \left(d + \tfrac{2}{3} h\right),$$

or, for a length of one metre

$$= 2{\cdot}953 \sqrt{h} \left(d + \tfrac{2}{3} h\right),$$

we shall have discharges as follow, with basin gauge at 26·70 :—

TABLE 219.—KOSHESHA ESCAPE DISCHARGES.

River at	Million cubic metres per day.	Cubic metres per second.	Metres of Opening required for 100-million cubic metre discharge per day.
26·40	0·4054	4·692	246
26·00	0·5920	6·846	169
25·70	0·6814	7·887	147
25·40	0·7480	8·655	
25·00	0·8089	9·323	
24·70	0·8419	9·745	
			Metres of Opening required for 150 million cubic metres.
24·40	0·8643	10·004	174
24·00	0·8806	10·192	170
23·70 and below	0·8841	10·233	169

Now the river has only been recorded as above R.L. 26·0 on two occasions during the last thirty years, whilst a large discharge with a low river is most important. It is evident, then, that the 174 running metres of waterway for 150 millions should rule the length.

Assuming a round number of 180, thirty-six bays of 5 metres, or sixty bays of 3 metres, are required. (It was decided to build it of sixty bays of 3 metres.) With the basin at 26·70, we have the following figures:—

TABLE 220.—KOSHESHA ESCAPE DISCHARGES.

River Level before Discharge.	First Discharge, million cubic metres per day.	Raised River Level in consequence of Discharge.	Decreased Discharge, million cubic metres per day.	Remarks.
26·00	106½	26·40	73	Must be supplemented by partially opening lower series.
25·50	131	26·00	112	
25·00	145½	25·70	123	
24·00	158½	24·90	148	
23·00	159	24·10	158	
22·50	159	23·70	159	

The effect on the level at the Delta Barrage of opening at the above levels is shown in the following table :—

TABLE 221.—BARRAGE GAUGES AS AFFECTED BY KOSHESHA.

Basin Gauge. R.L.	River Gauge at Wasta, five kilometres below Koshesha. R.L.		Corresponding to Barrage. R.L.		Rise at Barrage, in metres.
	On Opening.	After Opening.	Before Opening.	After Opening.	
26·70	26·00	26·40	17·50	17·90	0·40
,,	25·50	26·00	17·00	17·50	0·50
,,	25·00	25·70	16·50	17·20	0·70
,,	24·00	24·90	15·50	16·40	0·90
,,	23·00	24·10	14·50	15·60	1·10
,,	22·50	23·70	14·00	15·20	1·20

The design for gates has been selected with a view to simplicity, combined with quick opening for the upper tier, and preference has accordingly been given to horizontally pivoted falling gates for the upper series, and direct lifted gates in vertical grooves for the lower sluices."

TABLE 222.—COST OF KOSHESHA ESCAPE.

Description of Work.	Quantity.	Cost.
	cubic metres.	£
Excavation in foundations	68,708	2,102
Earthwork in approach channels and banks	154,300	4,977
Brick masonry	7,688	7,719
Rubble masonry, ordinary	17,768	14,215
Rubble masonry, in Portland cement	2,108	3,374
Concrete	146	146
Ashlar masonry	1,324	5,694
Dry rubble masonry	16,245	5,265
Unwatering	...	1,152
	lineal metres.	
Piling	549	3,323
Ironwork	see below	13,413
Woodwork	...	560
Hutting	...	574
Sundries	...	105
	Total	£62,619

Rates paid for Work.—The rates paid for different descriptions of contract work were the following:—

Earthwork	3¼	piastres	per cubic metre.
Brick masonry	100	,,	,,
Rubble masonry, ordinary	80	,,	,,
Rubble masonry, in cement	160	,,	,,
Dry rubble masonry	55	,,	,,
Dry rubble masonry with Government stone	15	,,	,,
Ashlar masonry	430	,,	,,
Piling	600	,,	per lineal metre.
Wooden gangways	700	,,	per arch.
Timber for winch railway	20	,,	per cubic foot.

IRONWORK.

	Quantities.	Rates, piastres.	Cost. £
Wrought iron	367·50 tons	1975	7,258
Cast iron	205·80 ,,	1425	2,932
Timber, teak	381·60 cubic feet	100	382
Iron rails	573·30 yards	20	114
Phosphor bronze	6360 lbs.	9	572
Chains	11·057 tons	2050	227
Steel	4·58 ,,	2470	113
Felt	1172 square feet		10
	Total		11,608
Winches	2	£668	1,336
			12,944
Other iron, and cost of erection			469
	Total cost, ironwork		£13,413

The regulator at the 26th kilometre of the Rashwania Canal (Plate XXXIX.), designed and built by Mr Wilson, is a good example of the type of work employed on the basin canals. The regulation is by means of horizontal sleepers. The sleepers are of the following dimensions and design:—

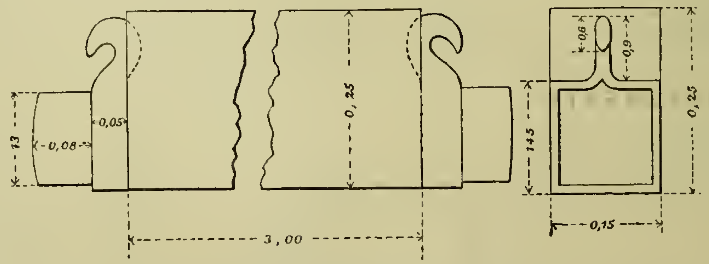
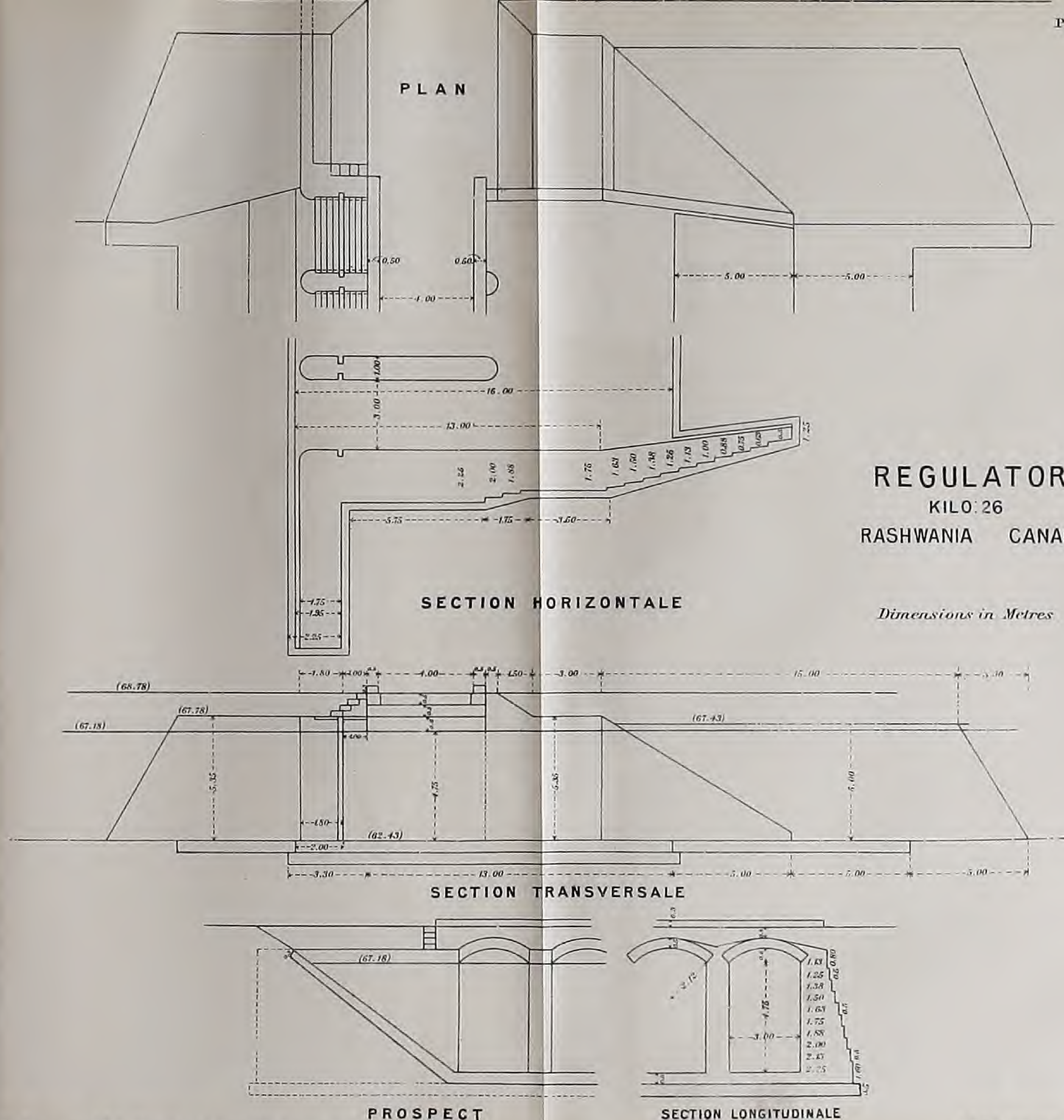


FIG. 128.—Scale 1/10. Horizontal Sleeper.



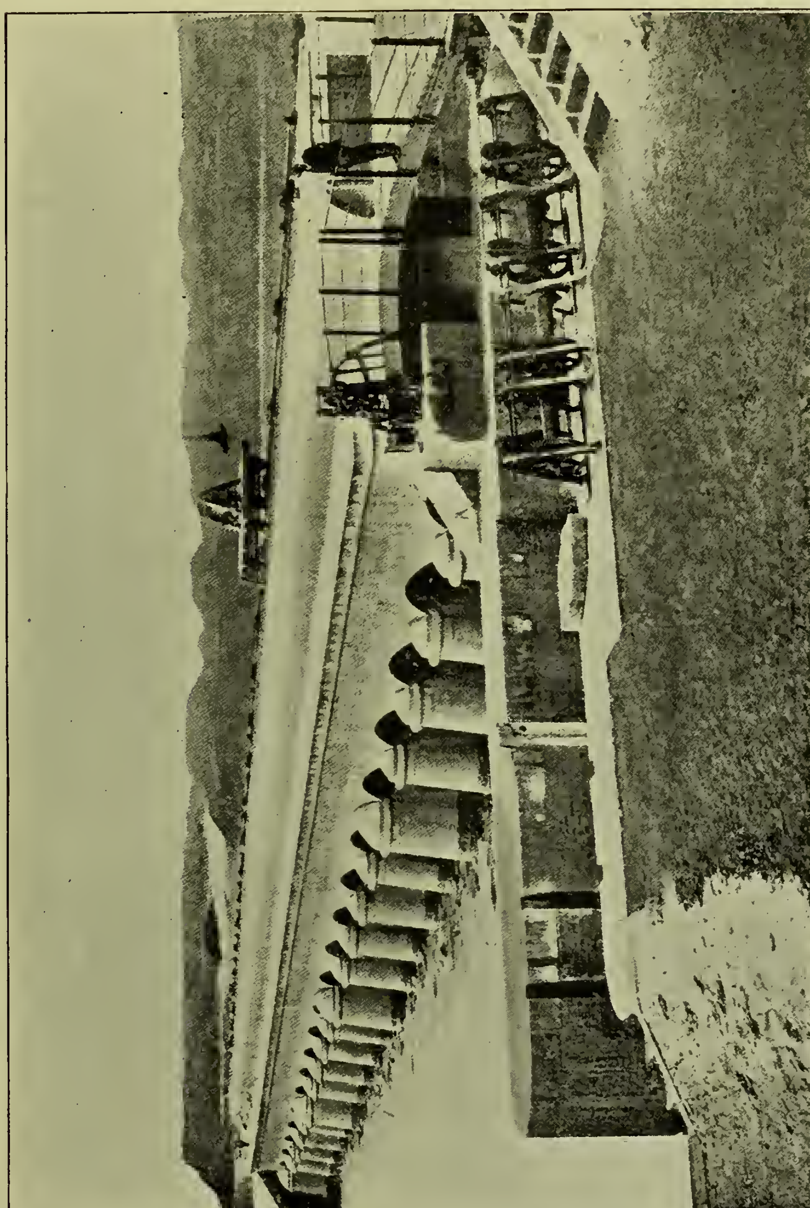
REGULATOR.

KILO: 26

RASHWANIA CANAL.

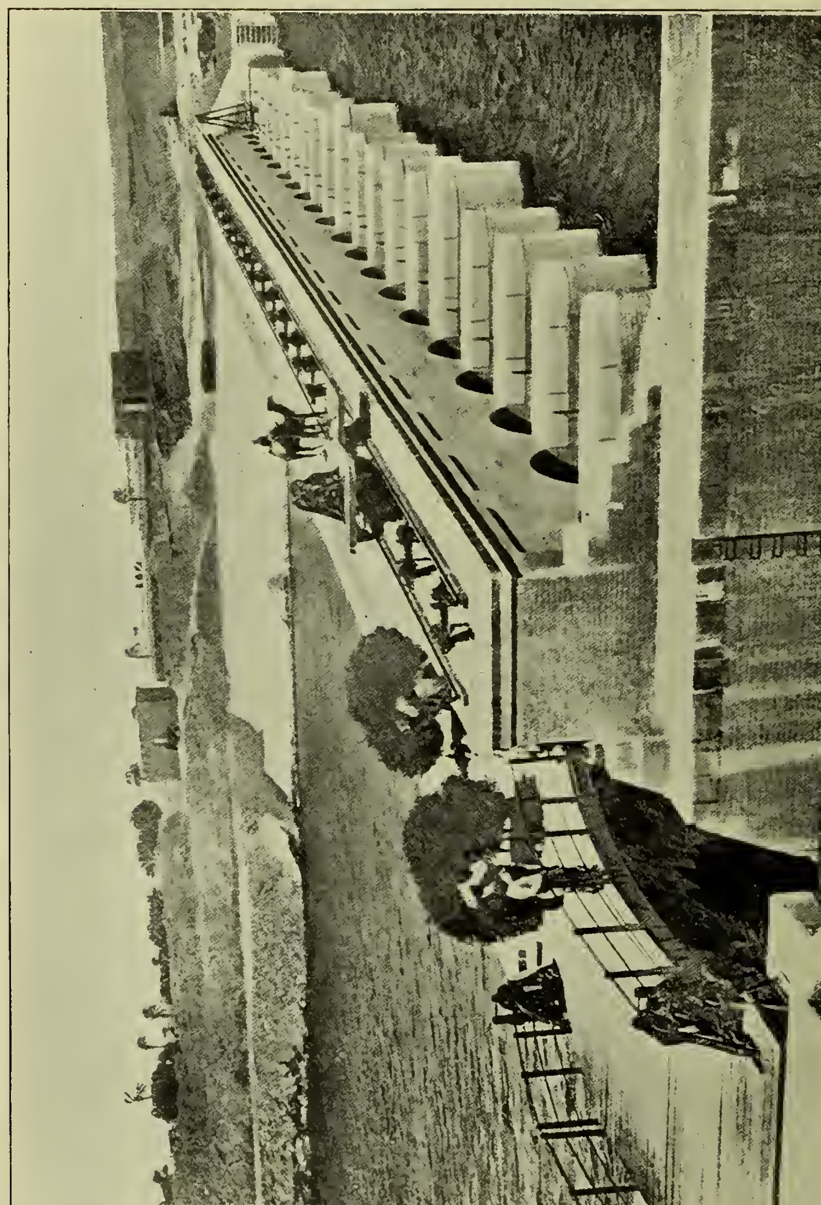
Dimensions in Metres

E & F N Spon Ltd London



Yusufi Canal Regulator (Downstream).

PLATE XLI.



Yusufi Canal Regulator (Upstream).

"*The Regulators on the Yusufi Canal.**—Between 1898 and 1901 Sir A. L. Webb, then Inspector-General of Irrigation, designed these regulators on the Yusufi Canal in Middle Egypt for the improvement of the basin-irrigated lands west of the above canal. These basins covered an area of about 105,000 acres, and contained some of the poorest and most neglected land in Upper Egypt. Of the whole area only 11,000 acres were properly irrigated. The remaining 94,000 acres received only four or five days' water per annum when the discharge water of the basins swept down the canal and covered the land with its overflow. This discharge water was quite clear and left no deposit to enrich the soil. In 1895–96, during the Land Tax adjustment operations, these lands were valued at £15 per acre. At the same time the Ministry of Finance was informed that a very moderate expenditure of money would greatly enhance the value of the land. Sir Arthur Webb, as Inspector-General of Irrigation in Upper Egypt, prepared the project for providing these lands with first-class basin irrigation. The late Mr Verschoyle, C.M.G., who succeeded him, and Mr Clowes built these weirs on the Yusufi Canal and supplied canals, banks, regulators, and escapes to the basins. At an expenditure of £245,000 they have supplied suitable basin irrigation to these 94,000 acres, which were worth £15

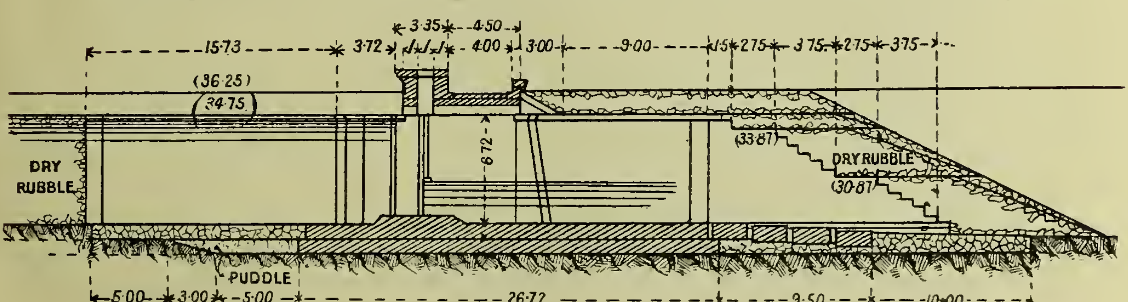


FIG. 129.—Bahr Yusuf Regulator. Cross Section. Approx. Scale $\frac{1}{400}$.

per acre, and rose immediately to £40 per acre. These lands have experienced a rise in value of £2,350,000.

Of the total expenditure of £245,000, about £175,000 were spent on canals, dykes, and regulators on the 94,000 acres, at a rate of £2 per acre; while £70,000 were spent on the three weirs. Two of the weirs have twenty openings of 3 metres each, while the third has twenty-five openings of 3 metres each. Navigation is allowed for everywhere. Plates XL. and XLI. contain two views of one of these regulators, from the upstream and downstream, and fig. 129 gives a cross section.

The Yusufi Canal has a bed width of 100 metres, maximum depth of water 6 metres, and discharges as a maximum 900 cubic metres per second. The regulators are designed to discharge the maximum volume with a velocity of 2 metres per second. The works embody late Egyptian practice and are good examples of it. The size of openings, the widths of the piers, the width and thickness of floor, the extent of pitching up and downstream, the masonry blocks, the system of regulation, the safety grooves, and the sizes of the locks, are all typical of such works on the canals of the country.

It will be noticed that the openings are 3 metres wide each and not 5 metres as in the Tewfiki Canal head. This is owing to the fact that in out-of-the-way

* We again quote from *Public Works.*

localities it is convenient to be able to regulate the safety grooves with horizontal wooden sleepers. With 5-metre wide openings, frames and verticals must be used. Each of the weirs with twenty openings cost £22,000, while the weir with twenty-five openings cost £24,000."

112. **The More Recent Regulators.**—Good types of recent practice are the regulating heads of the Kilabia and Mataana Canals taking off from above the Esna Barrage. They were designed and built by Mr John Langley, Inspector-General of Irrigation for Upper Egypt. We quote from Mr Langley's report for 1908 (see Plates XLII., XLIII., XLIV., and XLV.):—

"The area that will derive direct benefit from the Esna Barrage by means of the two main supply canals is approximately 171,000 acres, of which 71,000 acres lie on the east of the Nile and 100,000 acres on the west. In addition to the area mentioned above, the remaining portion of Kena Province will benefit indirectly, as the extra water supplied to the southern systems will be available for passing on and completing irrigation to the north.

The main eastern canal has a total length of 70 kilometres of new and remodelled channels. It takes off the river 330 metres upstream of the barrage with a new head of four spans of 5 metres each. Its bed is R.L. 76·50, and bed width 18 metres. It joins the Kilabia Canal, which it follows in a single channel to Maala Canal head. From there to Kiba syphon it runs as a double channel following the alignment of the old Kilabia and Maala Canals, and from the syphon it again becomes a single channel following the alignment of the Maala Canal, till it tails into the Bayadia Canal at a short distance below its head. The alignment from here follows the Bayadia to Khuzam, which is the end of the main channel. The Bayadia section of the canal is of sufficient section, and for the present will require no remodelling.

The main western canal, with a total length of 90 kilometres, a head regulator of five spans of 5 metres each, bed R.L. 76·00, and bed width 17·00 metres (at present), passes for about 4 kilometres through Sheikh Fodeil basin and joins the Asfun Canal, which it follows till it joins the Fadilia Canal about 2 kilometres from its head. It then follows the Fadilia and Sayala Saharet Tukh till it tails into the Tukh Canal immediately downstream of its head regulator, and for the time being the project ends at this point.

The two main canals will not supply the total water required, as the Bayadia on the east and Fadilia and Tukh on the west will continue to draw direct from the Nile when levels permit, and the main canals will be used for completing the supply.

To enable this to be done, three main groups of regulators have been provided at the junctions between the main canals and the three canals above mentioned. Thus, by regulating on the main canal regulators, the old canals can draw from the Nile, while the southern basins are being filled from the main canals.

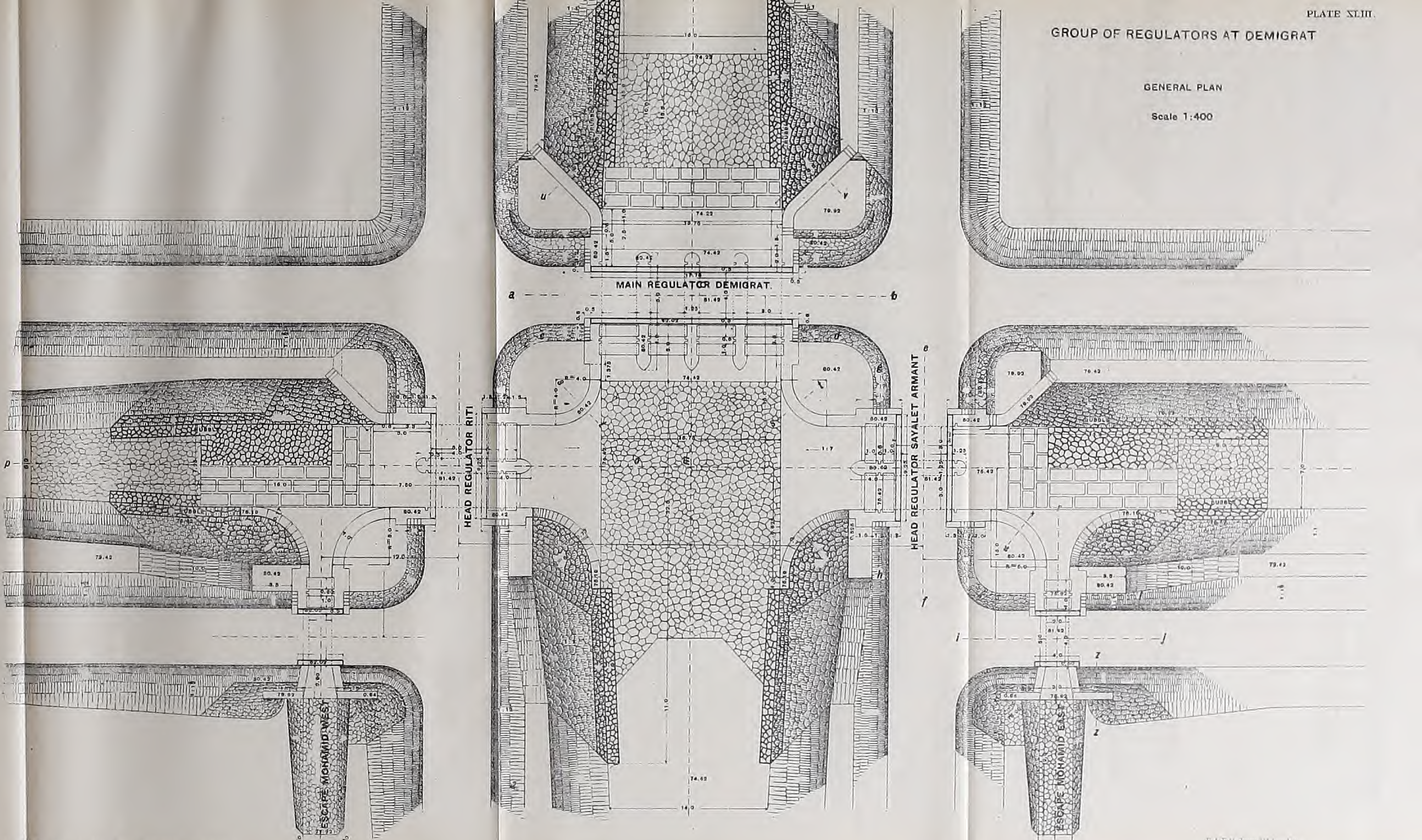
The flood level on which calculation is based is R.L. 81·00 metres downstream of the head regulators of both canals; so that the depth of water is 4·5 and 5 metres on the east and west respectively. The highest level upstream of the barrage is taken as R.L. 82·50 metres. The bed and water slope for the main eastern is 1 : 25,000,

Esna Barrage, Asfûn Canal Head (Downstream).

GROUP OF REGULATORS AT DEMIGRAT

GENERAL PLAN

Scale 1:400



To face p. 584. Willcocks and Craig Egyptian Irrigation

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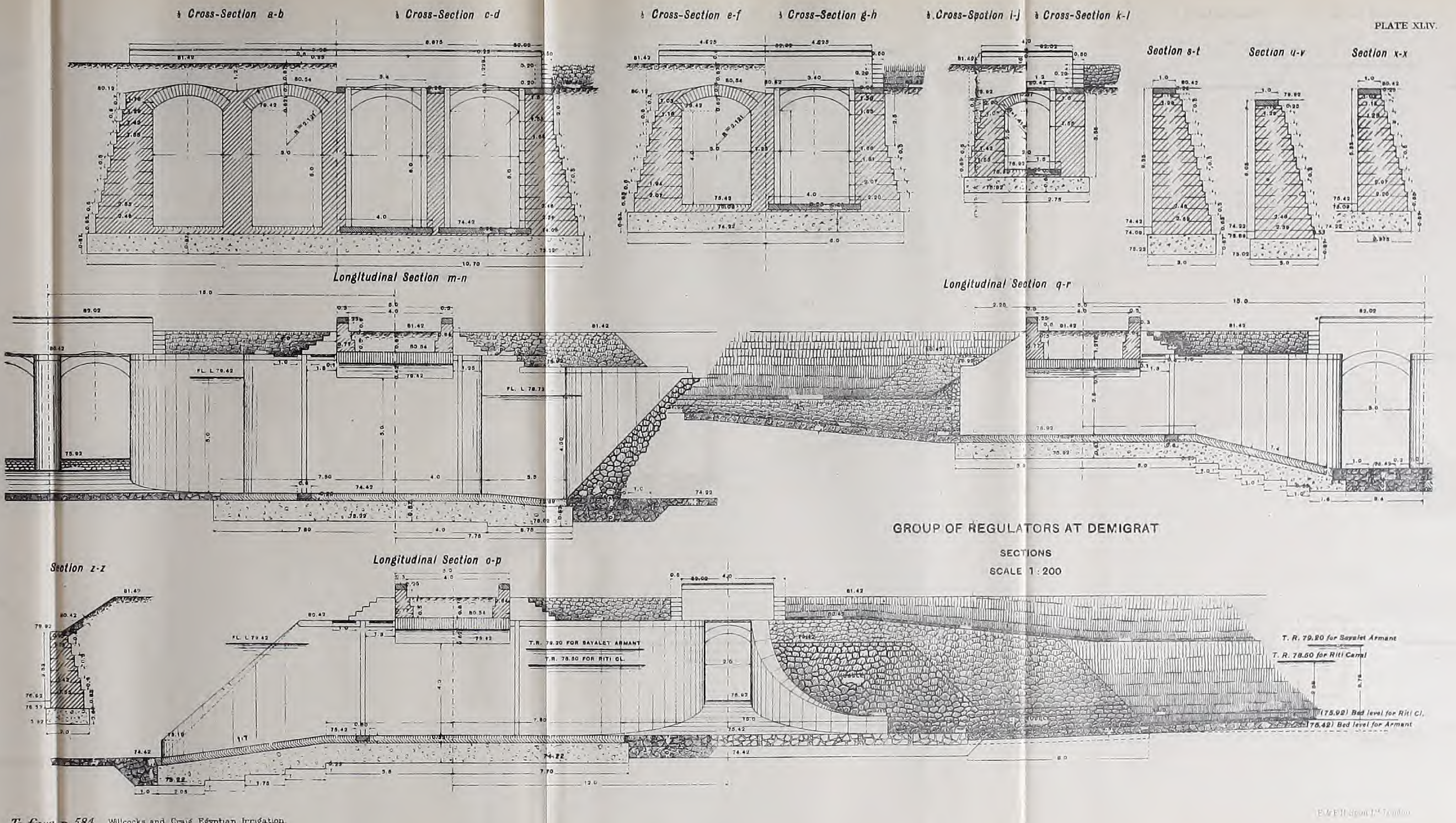
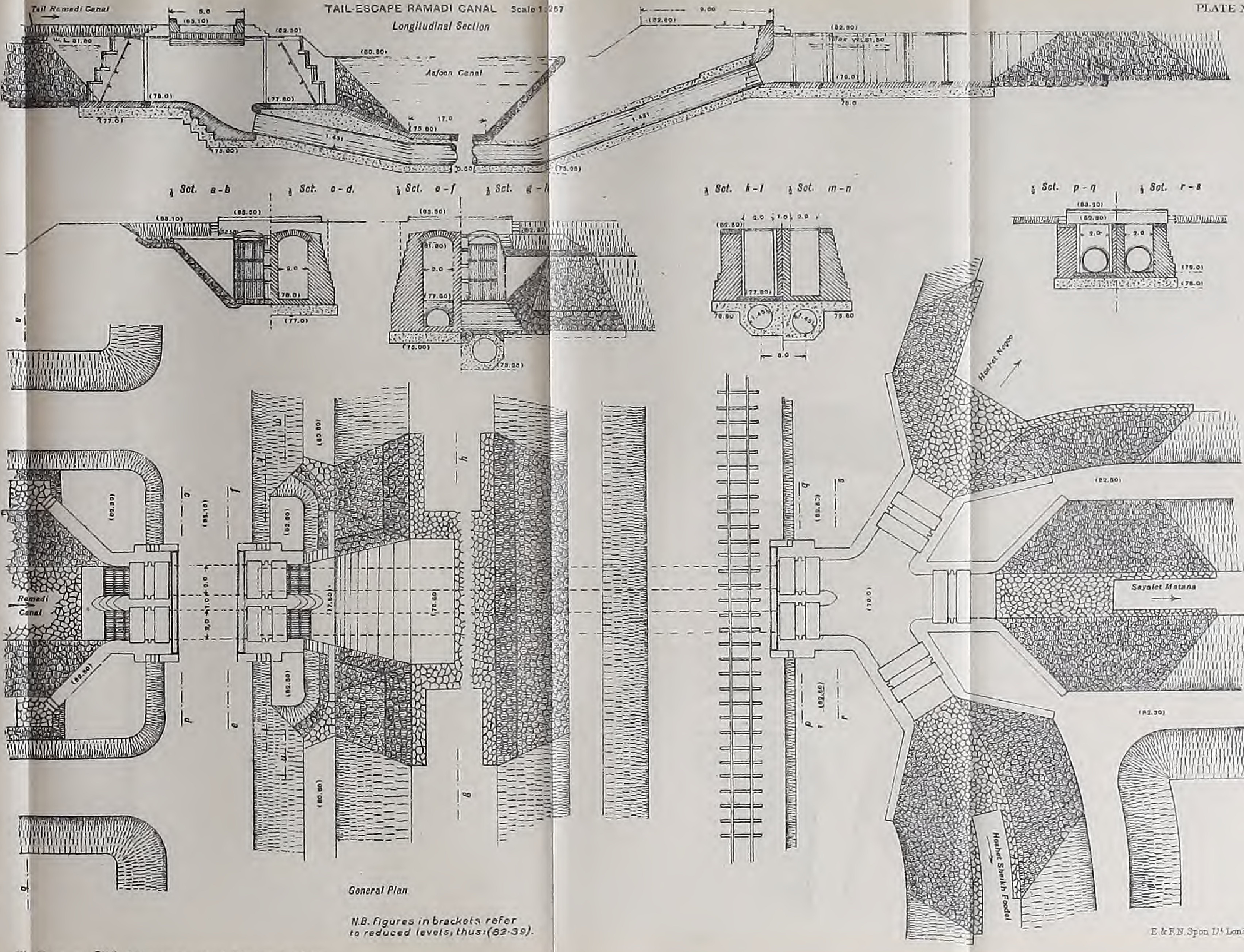


GROUP OF REGULATORS AT DEMIGRAT

SECTIONS

SCALE 1 : 200

To face p. 584. Willcocks and Craig Egyptian Irrigation.



To face p. 586. Willcocks and Craig Egyptian Irrigation

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TABLE 223.—ESTIMATE OF COST OF BASIN WORKS (ESNA BARRAGE).

Particulars of Works.	1907.		1908.		1909.		After 1909.			Total.	
	Quantities	Amount.	Quantities.	Amount.	Quantities.	Amount.	Quantities.	Rates.	Amount.	Quantities.	Amount.
	cubic metres	£	cubic metres	£	cubic metres	£	cubic metres	£	£	cubic metres	£
Ordinary earthwork . .	120,000	3,037	1,250,000	32,323	2,965,000	70,600	3,000,000	0·030	90,000	7,335,000	195,960
Excavation in gravel .	...	...	150,000	9,000	40,000	1,600	850,000	0·060	52,000	1,040,000	62,600
,, in rock . .	...	...	...	...	...	...	30,000	0·200	6,000	30,000	6,000
Transport of earth . .	...	...	...	...	...	...	200,000	0·020	4,000	200,000	4,000
Masonry works . .	7 works	9,516	47 works	32,730	70 works	34,000	30 works	...	20,000	154	86,246
Dry rubble . . .	...	...	1,150	565	22,000	7,500	10,000	0·30	3,000	33,150	11,065
Nile protection . .	...	1,210	12,870	4,173	...	...	...	...	...	12,870	5,383
Expropriation . . .	...	...	...	...	...	4,000	500 acres	70·000	35,000	560	39,000
Remodelling branch canals	...	...	...	...	...	...	...	...	30,000	...	30,000
Establishment and sundries	...	3,330	...	5,291	...	6,150	...	...	15,000	...	29,771
.		17,093	...	84,082	...	123,850	...	...	255,000	...	470,025
Contingencies .	...	...	...	...	...	...	...	...	...	...	30,000

Grand total for completing work up to Kift on the east, and Tukh on the west, £500,000

TABLE 224.—PARTICULARS OF CANAL CALCULATIONS (ESNA BARRAGE CANALS).

	Sections of Canals.	From kilometre to kilometre.	Length.	Areas served.	Slope Surface.	Particulars of Canal. Water Depth.	Bed Width.	Sectional Area.	Wetted Perimeter.	Hydraulic Mean Depth.	C.	V. Metres per second.	Discharge, cubic metres per second.	Maximum Area that Canal can serve in 45 Days.	Remarks.
			kilos.	acres		m.	m.	sq. m.	m.	m.				acres	
Western Canal.	Head Regulator to Om Adas Canal	0·000– 3·600	3·600	78,562	(1 : 20,000, 5 centimetres per kilo)	5·0	17·0	110·00	31·14	3·53	62·0	0·825	90·7	83,962	Very clean canal.
	Om Adas Canal to Sayala Matana	3·600– 7·560	3·960	63,762		5·0	17·0	110·00	31·14	3·53	49·0	0·652	71·7	66,374	Drop of 0·70 metre for water levels and 0·20 metre for bed levels.
	Sayala Matana to Dimigrat Regulator	7·560–31·600	24·040	55,762		5·0	14·0	95·00	28·14	3·38	48·7	0·633	60·1	55,635	
	Demigrat Regulator to Makhar Canal	31·600–37·640	6·040	48,062		4·5	15·0	87·75	27·75	3·16	48·3	0·609	53·4	50,505	
	Makhar Canal to Dabaia feeders	37·640–44·890	7·250	45,862		4·5	14·0	83·25	26·73	3·11	48·2	0·603	49·6	45,91	
	Dabaia feeders to Fadilia Regulator	44·890–55·262	10·372	36,262		4·5	14·0	...	...	...	...	...	...	...	Ordinary canals.
	Fadilia Regulator to Gurna Canal	55·262–66·500	11·238	44,747		4·5	14·0	...	...	...	...	...	...	...	
	Gurna Canal to Shaat Canal	66·500–67·770	1·270	42,447		4·5	13·0	78·75	25·73	3·06	48·1	0·596	46·9	43,416	
	Shaat Canal to Kamula Canal	67·770–69·720	1·950	35,147		4·5	11·0	69·75	23·73	2·94	47·9	0·580	40·5	37,492	
	Kamula Canal to Syphon Tukh	69·720–90·474	20·754	26,247		4·5	8·0	56·25	20·73	2·71	47·4	0·550	30·9	28,607	
	Syphon Tukh to junction Tukh Canal	90·474–91·000	0·526	23,447		4·5	8·0	...	...	...	...	...	...	...	
	Tukh Canal	91·000 to tail	...	36,400		4·5	...	...	...	...	...	...	...	...	
Eastern Canal.	Head Regulator bifurcation	0·000–21·134	21·134	52,000	1 : 25,000 (4 centimetres per kilo)	4·5	18·0	101·25	30·73	3·29	48·6	0·558	56·5	...	
	Beginning bifurcation to Salamia branch (Kilabia Canal)	21·134–29·160	8·026	52,000		4·5	10·0	65·25	22·73	2·87	47·7	0·510	33·3	...	
	Beginning bifurcation to Salamia branch (Maala Canal)	...	...			4·5	7·0	51·75	19·73	2·62	47·2	0·481	24·8	...	
	Salamia branch (Bayadia Canal)	29·160–47·419	18·259	41,450		4·5	14·0	83·25	26·73	3·11	48·2	0·535	44·5	...	

and for the western 1 : 20,000. The first regulator on the main eastern canal is at Kiba (kilometre 29) and on the western at Dimigrat (kilometre 30).

The estimated time of filling basins is forty-five days.

The canal sections are calculated with Manning's coefficients for ordinary canals; an exception, however, is made on the first reach of the western canal, where C is taken as for clean canals, whereby the bed is 17 metres instead of 21 metres; this was done for the present for economy's sake, as the canal on this reach is new and of good section.

The masonry works are all designed larger than present requirements need, so that if eventually it is found necessary to extend, slight alterations in the section of canals will enable this to be done: the present object being to complete all junctions so as to make it possible to utilise the barrage. This has been done; and when the works proposed for the 1909 programme are complete, the barrage can be used to augment supply the following season should it be found necessary.

The figures in Tables 223 and 224 show that 76 per cent. of the area on the east and 86 per cent. on the west would have got water direct from the Nile in 1907 if the barrage existed, whereas only 45 per cent. on the east and 40 per cent. on the west actually did.

During the last ten years the total area left unirrigated in the basin system affected by the barrage was 210,841 acres, or an average of 21,000 per year; if the whole of this is saved in future, assuming the value of the crops at only £5, the benefit to the country by these works is £105,000 per year."

The Rayah Menufia Head Regulator.—The old regulator was originally built about 1850 by Mougel Bey, and had 6 openings of 4·17 metres each. In 1887 Colonel Western and Mr Reid added a seventh opening of 4·17 metres and a lock 50 metres × 8 metres. It was built on sand, which was gradually washed out by springs; and on the 1st January 1910 the regulator collapsed. Everything disappeared except the additions of 1887. The regulator at the time was closed and was holding up 3·40 metres.

A commission, presided over by Mr C. E. Dupuis, sat on the work and decided to begin immediately the construction on a diversion of a new head of which Plate XLVI. gives a photograph.

The new work was begun forthwith under the immediate supervision of Mr M. MacDonald, C.M.G., Director-General of Construction and Reservoirs, and was completed in August of the same year: a very creditable performance indeed.

The new work consists of 9 openings of 5 metres each. The piers are 15·5 metres long and 2 metres wide. The R.L. of the floor is 10·50 metres and of high flood 18·50 metres, giving a maximum depth of water on the floor of 8 metres. The piers and abutments rise to R.L. 19·30 metres, and are consequently 8·80 metres high.

The floor is 38 metres wide and 3 metres deep. The bottom metre is cement concrete, and the two upper metres are of rubble masonry in cement mortar of 1 cement to 4 sand.

Between the openings and for a depth of 40 centimetres the surface of the floor is of ashlar and the remaining portion of 2 to 1 cement concrete for a similar depth of 40 centimetres.

The lock is 8 metres wide, and the lock wall 4 metres wide.

The upstream pitching is 27 metres wide overlying puddle, and that on the downstream side 25 metres wide and 2 metres deep.

Each opening is regulated by three gates : two of 3 metres height each, and the third of 1·50 metres. They work in triple cast-iron grooves which all go down to the floor.

The following account of the construction is from Mr MacDonald's report, and is extracted from the *Irrigation Report* for 1910:—

"Excavation on the site of the regulator was commenced on the 19th January, and a few days after 5000 men were engaged in this work. Concurrently with the work on the site of the regulator, excavation was commenced along the whole line of the canal diversion, and extending from surface level to the level of the water table, so that the removal of the under-water material by dredgers might be proceeded with.

The general dimensions of the pit to be excavated for the regulator proper were 100 metres by 100 metres at foundation level; thereafter on the eastern and western sides, slopes of $2\frac{1}{2}$ to 1 ran to the surface, at which level the limits of the excavation measured nearly 170 metres from side to side.

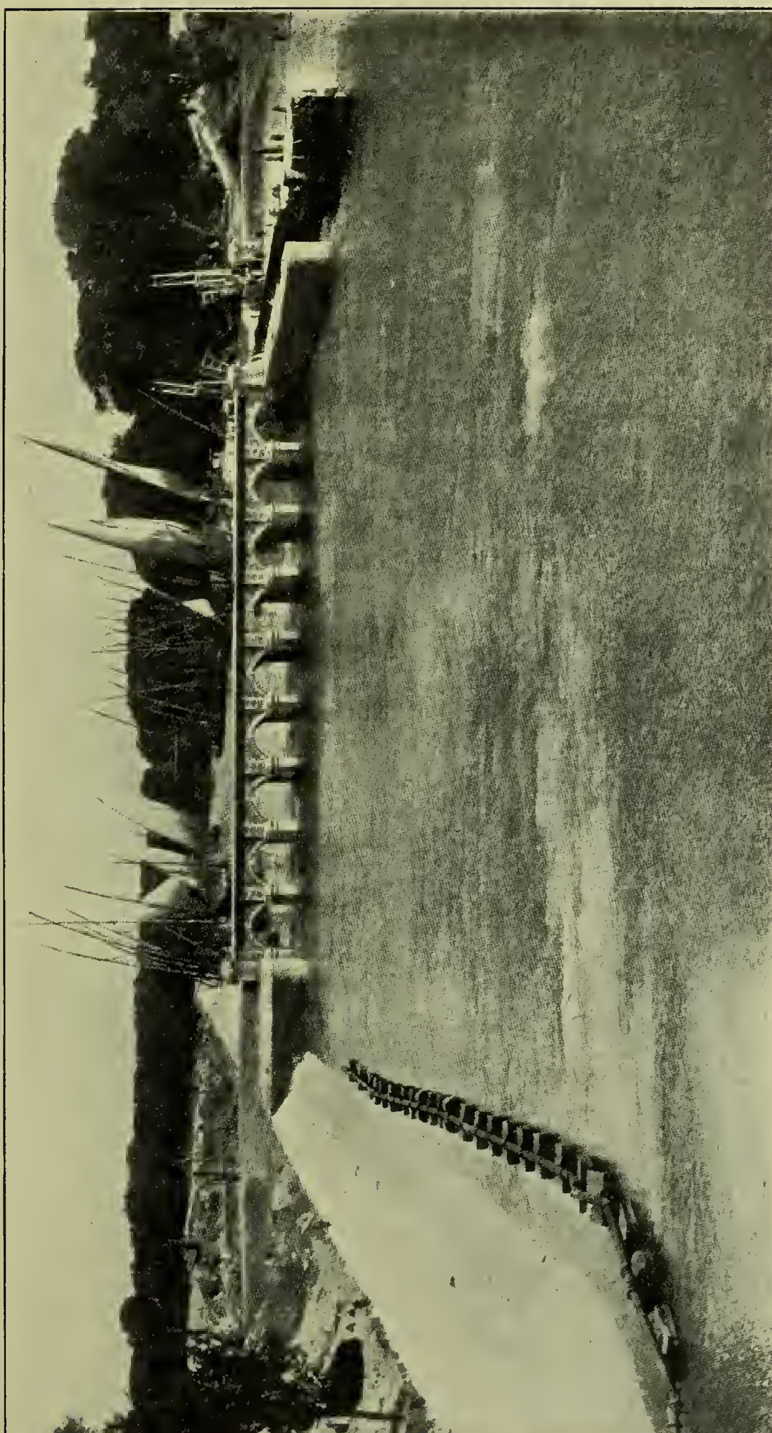
At the limits of excavation north and south of the regulator, or on the line of the canal diversion, earthen dams of large size were left as protecting barriers to be removed afterwards by dredgers.

By the end of March, out of 215,487 cubic metres of excavation on the site of the regulator, 172,000 cubic metres had been removed—the general level of the bottom being R.L. 10·00.

At R.L. 13·50 water made its presence felt, and as R.L. 12·00 was reached clay beds were come upon of an average thickness of from 0·5 metre to 1 metre. Upon the removal of those clay beds a black silty sand made its appearance, through which water came in unusually large quantities in the form of springs. These had to be contended with until the completion of the excavation in April.

At one period, over the central portion of the excavation, the foundation became so spongy that it was impossible for either camels or men to stand upon it. On the site of the lock and towards its northern end a comparatively good foundation of white sand was come upon, and after the level of the excavation had become general over the whole area those portions which had become unworkable through springs gradually became more consolidated and fit to be removed.

It became necessary to commence pumping on the 28th of February, one 12-inch diameter pump being employed at the north-eastern side of the work on that date. During March the number of pumps was increased to six, all of 12-inch diameter, and as it was found that their united efforts were at times barely sufficient to keep the water within workable limits, the number was increased to eight. The sump wells were arranged at the four corners of the work, with two boilers and pumps on each stage.



Rayah Menufia, New Head Regulator.

From the 1st April onward, eight 12-inch diameter pumps and one of 10-inch diameter were necessary to cope with the volume of water. The bulk of the pumps were removed after the 22nd of June. By 2nd July all the pumps had been removed, and the water allowed to rise.

It is estimated that during the period the pumps were at work, or between 28th February and 2nd July, practically 15,000,000 cubic metres of water were pumped out.

During April the influx of water from all sides was of such volume that the side slopes became flattened and overlapped the limits of the foundation. It became necessary to construct hastily a sand-bag toe at the foot of all the slopes. The excavation was removed to a sufficient depth to enable piling to be commenced on the 7th April.

700 tons of cast-iron piles were driven so as to form a continuous barrier around the whole of the base of the regulator.

Four piling engines completed this work by the 17th May; the operation being rendered more than usually difficult by reason of the soft nature of the material upon which the heavy piling frames had to rest. Bases of sand bags had generally to be laid for the support of the frames. In spite, however, of the soft nature of the material, at foundation level the driving was generally hard. The average drop of a pile, under blows from a monkey weighing 30 cwts. and with a fall of 3 feet, was 1 centimetre.

Thereafter the joints were cleaned out by means of a water jet under pressure, and cement grout introduced so that the piles for the whole of their length became a water-tight apron.

The piles, which were specially ordered from England, were of cast iron and weighed over 19 cwts. each; their extreme length was 5 metres.*

The two main lines of piles across the regulator are 35·50 metres apart.

Concreting commenced at the southern entrance to the lock on 18th April. An attempt was made to deposit the concrete in the dry by pumping out the water contained between the piles, but it was found that when the water was reduced to within 30 centimetres of the foundation level, the bottom rose in proportion as it was removed, so that the ultimate level could not be reached.

In conjunction with this, springs became so numerous as to make it risky to deposit concrete, and accordingly it was decided to allow the water to rise to within 20 centimetres of the pile heads, and deposit the concrete in one layer through the water. Despite this mode of procedure, however, as the concrete advanced single springs made their appearance at various points of the foundation. If these were of any volume, the treatment adopted was to encircle them in temporary wooden boxes kept to such a level as ensured that, whilst there was a free flow of water, no sand was carried up along with it; thereafter building round the springs with rubble masonry until the head of water was stopped. The hole or well thus formed was then filled with fresh concrete deposited through a chute, or in some cases the water was pumped out and the concrete deposited in the dry.

Particular care was taken to place in the foundation regular lines of grouting pipes, these being of 2-inch, 2½-inch, and 3-inch diameter, and at all points where

* We consider that steel piles of the Lackawanna type would have been much cheaper and better.

the least suspicion of a spring appeared. These pipes were, after the building had been completed, filled with cement grout in the proportion of 1 of cement to 1 of water, forced into the pipe under a pressure of from 15 to 20 lbs. per square inch.

Besides the pipes in the foundation proper, a series was carried through all the piers and abutments to their finished level so that at any future time grout may be applied to the foundation at these points.

The total quantity of concrete was 5020 cubic metres, and the work was completed on the 30th of May.

The sand was got from the river in the vicinity of the Rosetta weir.

An average number of seven stages were worked, all the concrete being fixed by hand, in the proportion of 1 of cement, 2½ of sand, and 5 of broken metal.

As soon as a workable stretch of concrete foundation had been deposited and allowed to set—or in a week's time—the rubble masonry in the floor was commenced.

Throughout the course of the work it was arranged that the concrete base should be about ten days in advance of the rubble building; this process answered admirably.

There were 9585 cubic metres of floor masonry, which was finished on the 4th of June.

The largest number of native masons employed at any time was 180, and the average rate of building per day over the whole period occupied was 228 cubic metres.

The main arches measure 8·118 metres in width, and are formed in concrete of 5 to 1; the downstream faces being finished in ashlar of the same dimensions and appearance as that of the upstream arches.

In order to provide against possible cracking of the concrete in the arches, two joints of stiff brown paper were introduced so as to divide the arch into three separate segments.

The masonry in superstructure was commenced on the 10th May, and was completely finished by the 30th July. The quantity includes 1258 cubic metres of ashlar, and 10,759 cubic metres of rubble masonry.

The Behera Company commenced the dredging of the northern approach to the regulator in February, and removed by suction dredgers 86,250 cubic metres of material.

The greater portion of the dredged material was deposited by these dredgers on the piece of land adjacent to the new canal on the west bank.

In June a barge with a powerful pump was introduced into the cut, the outer end of which was then sadded off, and the water so reduced that the pitching of the side slopes was successfully laid down. Thereafter this Company's dredgers removed both earthen dams—that at the northern end of the cut and the dam adjacent to the regulator,—work on these being completely finished by the 30th July.

At the same time the dredgers belonging to the Egyptian Dredging Company removed from the southern cut 19,000 cubic metres of material, which was deposited in the old Menufia channel.

During July seven dredgers were at work on the new canal diversion—one

large bucket, one Priestman grab, and two suction dredgers of the Egyptian Dredging Company, and one bucket and two suction dredgers of the Behera Company.

All the cast iron and built-in work arrived from England in time to harmonise with the building of the masonry. The sills and quoins for the southern set of lock gates were set on the 24th May, and at intervals during this month and the beginning of June the gates for the penstock chambers, and the complete set of sills and quoins for the main head sluices, were set.

All the sluice gates had not arrived on the ground by the end of July, nor had the lock gates appeared. As the water was then rising, and it was imperative that the whole of the ironwork should be erected by the 26th August, there was no option but to erect the lock gates on a site adjacent to their ultimate position and drop them into place. Wooden trestles were constructed for this purpose. The lock gates arrived on the 7th August, and were immediately put together. On the 20th August the lock was closed to traffic ; a wooden grid was placed in the timber grooves to break the velocity of the water passing through the lock, and on the 21st inst. both of the southern leaves were successfully placed in position. On the 27th the lock was again closed to traffic, and the northern set of gates placed in position by the 1st September—the process being delayed somewhat by an accumulation of silt in the gate recess.

The setting of the sluice gates was commenced on the 22nd August, and by the 25th instant nine 3-metre and nine 1½-metre gates had been lowered into the openings to the top of the grooves, ready to be finally lowered into position by the crab. By the 27th inst. the remaining nine 3-metre gates had been lowered into position.

The crab winch arrived on the morning of the 25th ; the various parts were unloaded on the 26th, and by the 27th inst. the crab had been erected and was in working order, the total actual time taken to erect the crab being seventeen hours.

As on the 27th August regulation was necessary, the works were just completed in time.

The whole cost, including supervision, is expected to reach the amount of the provisional estimate of £135,000.

Messrs Aird & Co., represented by Mr H. H. M'Clure, were the contractors. Mr D. Kennedy was his assistant.

Messrs Ransomes & Rapier, the ironwork contractors, were represented by Mr G. S. Perry, A.M.Inst. C.E.

For the Government Mr R. G. Garrow, A.M.Inst. C.E., acted as resident engineer. Mr Garrow was assisted by Mr F. Kelty."

Fig. 130 gives the type of regulator designed and built by Ismail Pasha Sirry, Director-General of Conversion Works, on the basin conversion works between 1904 and 1909. It is taken by permission from M. Edmond Béchara's work, already quoted in CHAPTER VI.

Fig. 131 gives the type of regulating head proposed for the Mesopotamian canals, and is taken from the *Irrigation of Mesopotamia.*

We note here that many minor improvements have been effected in the

regulating grooves and gates originally designed by Colonel Western and Mr Reid. Messrs Maclellan of Glasgow and Glenfield & Kennedy of Kilmarnock have constructed many of these works and have full knowledge of recent Egyptian practice. Mr John Ashford, Superintendent

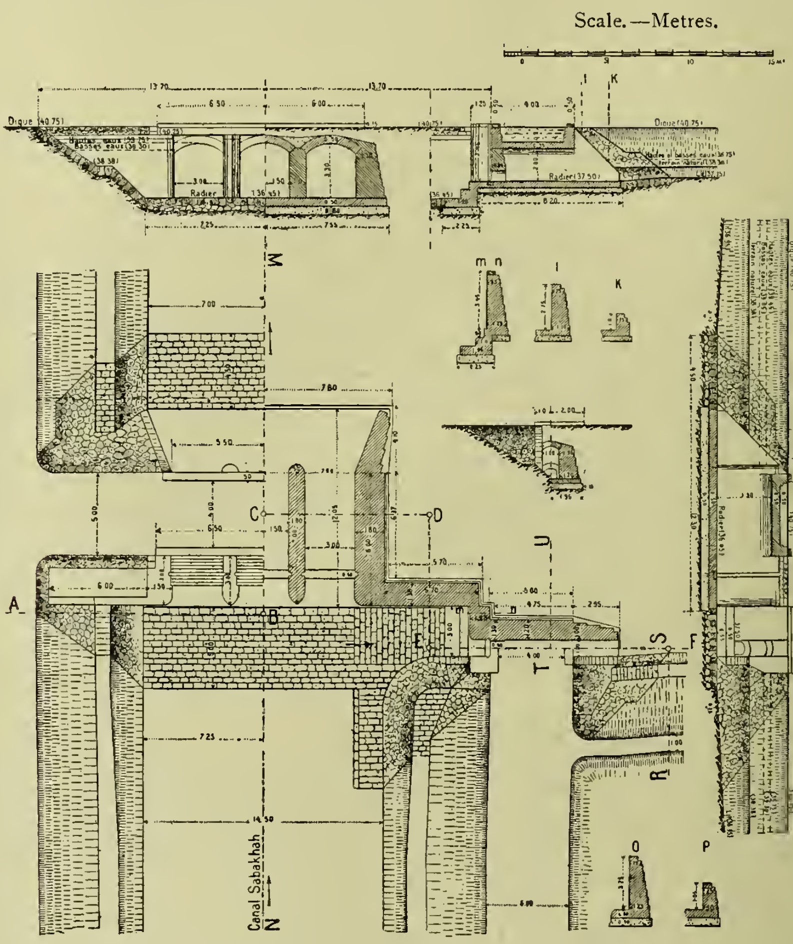


FIG. 130.—Regulator and Canal Head on Basin Conversion Works.

of the Government Central Workshop, Amritsar (India), has also made many improvements, and a reference to him is advised or to Messrs Glenfield & Kennedy. We only add that whatever type is finally chosen, let all the gates go down to the floor.

113. **Silt Deposits in Canals.**—Reference should be made to the last two paragraphs of CHAPTER IX., where the question is very fully treated.

114. **Navigation.**—Boat - building is the principal industry in the

country, and navigation employs more hands than anything except agriculture. The country, moreover, is flat, and the current generally in

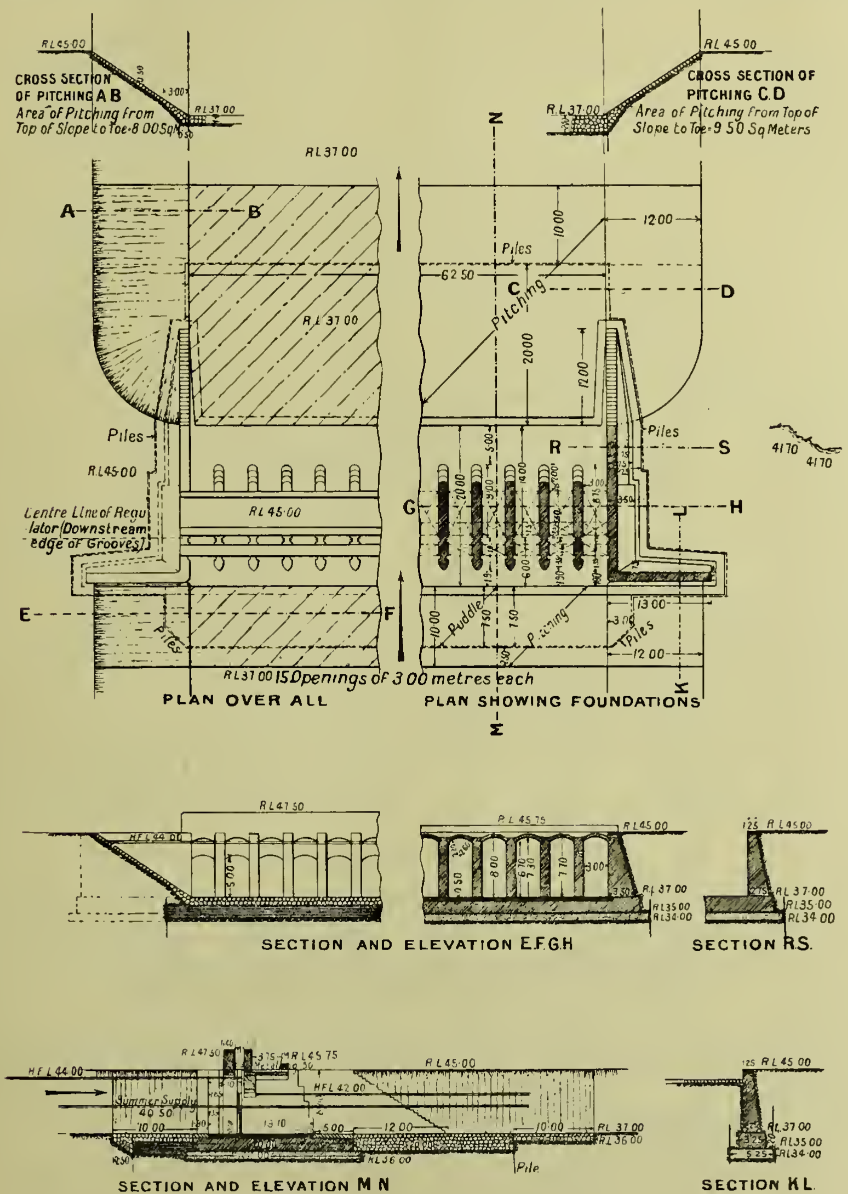


FIG. 131.—Proposed Upper Head for the Sakhlawia Branch (on the Euphrates). Approx. Scale $\frac{1}{500}$.

one direction and the wind in the other, so that navigation is easy. All tolls were removed in 1904 from bridges and locks, and navigation made free everywhere by Lord Cromer.

The following table gives dimensions of typical boats and steamers on the Nile :—

TABLE 225.—DIMENSIONS OF NILE BOATS AND STEAMERS.

Description of Boat.	Ardebage.	Extreme Dimensions.		Draught.		Height of Mast.	Remarks.
		Length.	Breadth.	Empty.	Full.		
		metres	metres	metres	metres	metres	
Cargo	1300	26·00	7·60	1·00	2·20	...	7 ardebs = 1
,,	1050	26·00	7·00	·80	1·90	15·90	ton.
,,	1000	24·00	6·60	1·00	2·00		To find
,,	907	23·60	6·61	·80	1·90		tonnage
,,	777	21·10	5·90	·80	1·90	16·15	divide
,,	724	21·46	5·70	·80	1·60	11·10	ardebage
,,	681	20·80	5·75	·80	1·60	14·20	by 7.
,,	658	21·00	6·14	·70	1·40	13·00	
,,	600	20·72	5·90	·70	1·40		
,,	556	19·80	5·60	·90	1·60		
,,	550	19·70	5·60	·70	1·60	12·80	
,,	500	19·40	5·34	·60	1·40		
,,	475	19·80	5·32	·80	1·40		
,,	455	18·67	5·26	·80	1·40		
,,	438	18·60	5·50	·80	1·50	11·60	
,,	406	19·30	5·20	·70	1·60		
,,	385	18·06	5·00	·70	1·40		
,,	369	17·51	5·03	·70	1·20	11·70	
,,	333	16·20	4·64	·70	1·50		
,,	320	16·70	4·70	·70	1·40		
,,	284	15·47	4·65	·60	1·20	10·50	
,,	228	14·72	4·34	·70	1·20	10·10	
,,	202	14·10	3·84	·60	1·10	6·50	
,,	188	13·35	3·74	·70	1·00	8·20	
,,	171	12·34	3·74	·70	1·00		
,,	130	13·67	3·71	·60	1·10		
,,	120	12·10	3·55	·60	1·00		
,,	98	11·20	3·40	·60	1·00	6·50	
,,	69	10·56	2·75	·40	·80	5·90	
,,	55	8·70	2·72	·40	·70	5·70	
,,	32	7·60	2·30	·35	·70		
,,	23	7·30	2·20	·30	·60	5·00	
,,	15	6·32	1·86	·30	·50		
Dahabias	?	35·40	5·70	·70	1·00	14·20	House-boats.
,,	?	33·50	5·80	·60	·80	14·50	
,,	1280	30·60	5·80	·70	·80	14·50	
,,	1241	29·40	5·64	·70	·80	14·00	
,,	1106	29·40	5·64	·90	1·00	14·00	
,,	587	22·90	4·50	·60	·70	11·00	
,,	?	30·00	4·70	·70	1·00	13·50	Registered 350 ardebs.
,,	250	16·90	3·20	·50	·60	7·20	
,,	263	17·00	3·04	·50	·60	8·00	

Complete information about navigation difficulties and tolls will be found in *Commission d'étude des droits de Navigation—Rapport*—(Cairo,

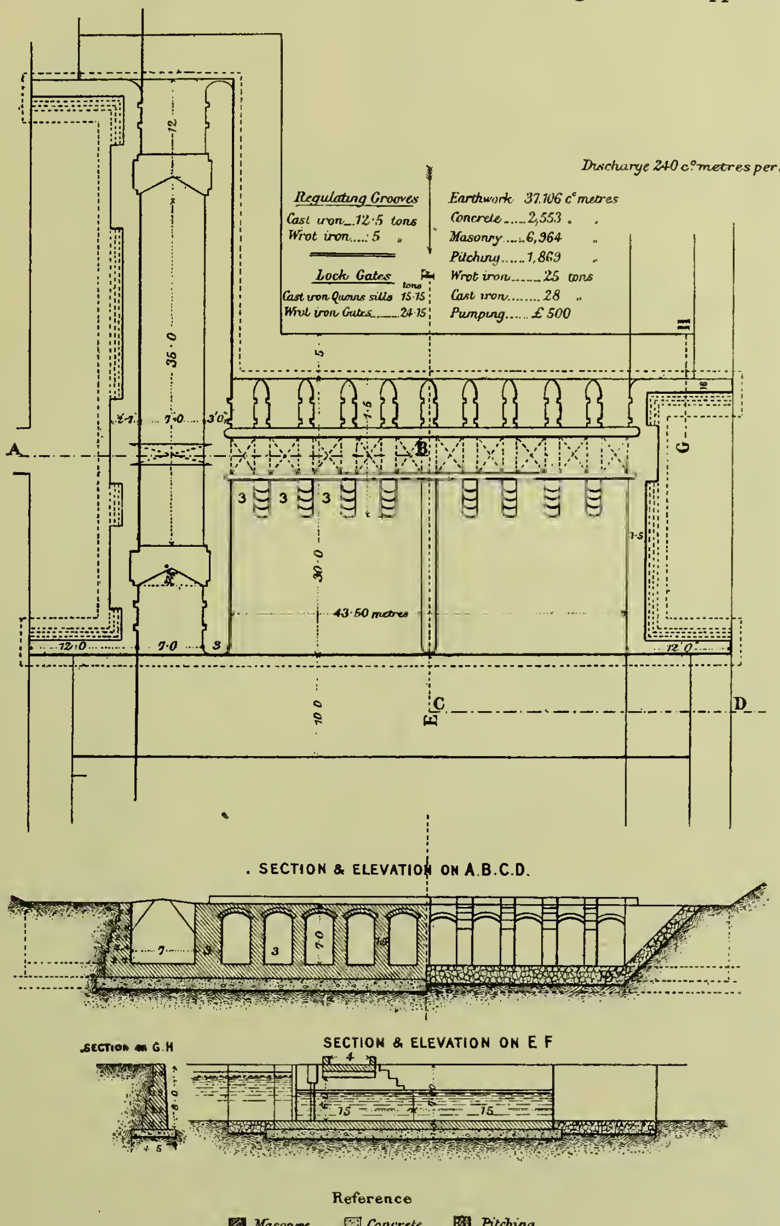


FIG. 132.—Melig Regulator on Bahr Shebin. Approx. Scale $\frac{1}{800}$.

1888), published by the Egyptian Government. Colonel Western was one of the Commission, and thoroughly examined the whole question.

Figs. 132 to 134 give details of the lock gates at the Melig regulator,

and the opening and shutting apparatus. It will be noted that the hollow

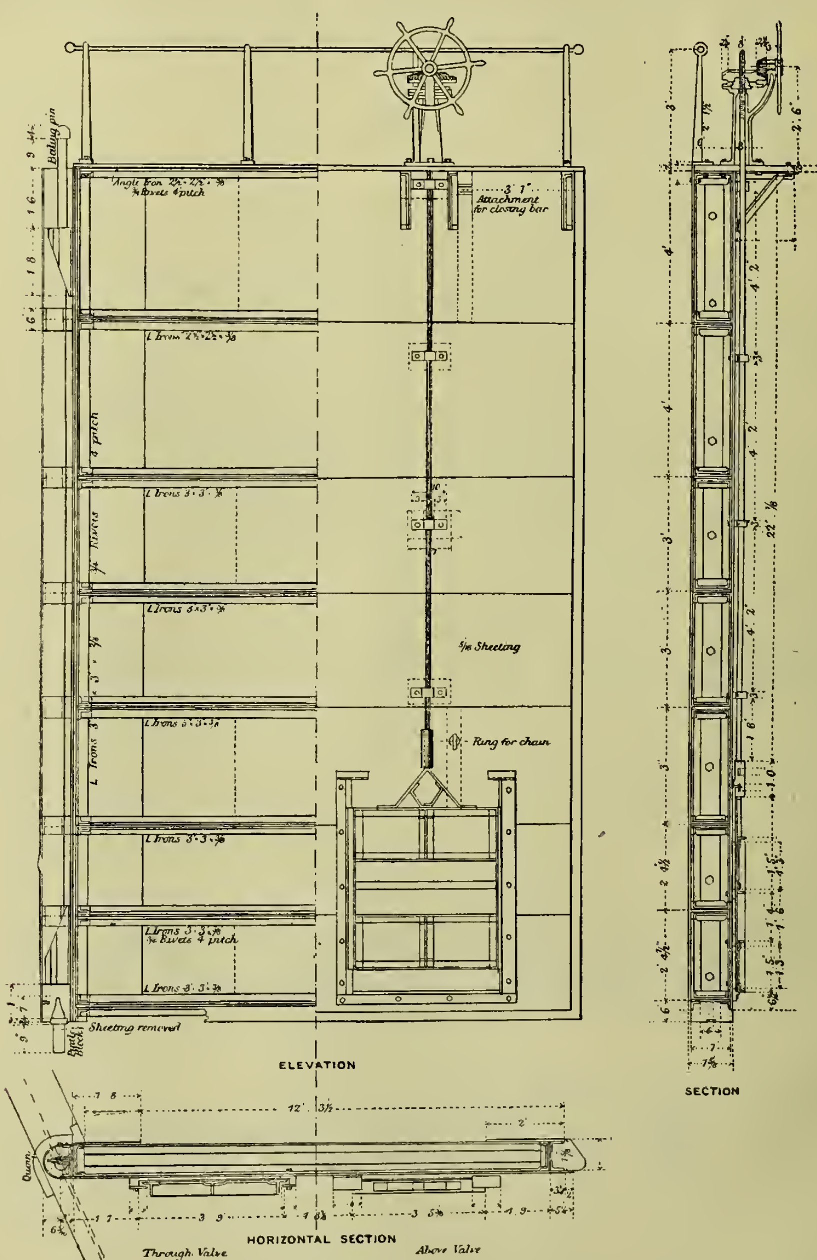


FIG. 133.—Melig Lock Gate. Dimensions in feet and inches. Scale $\frac{1}{60}$.

grooves and sills which are fixtures are of cast iron. The gates themselves are constructed of wrought iron. The valve openings are large compared

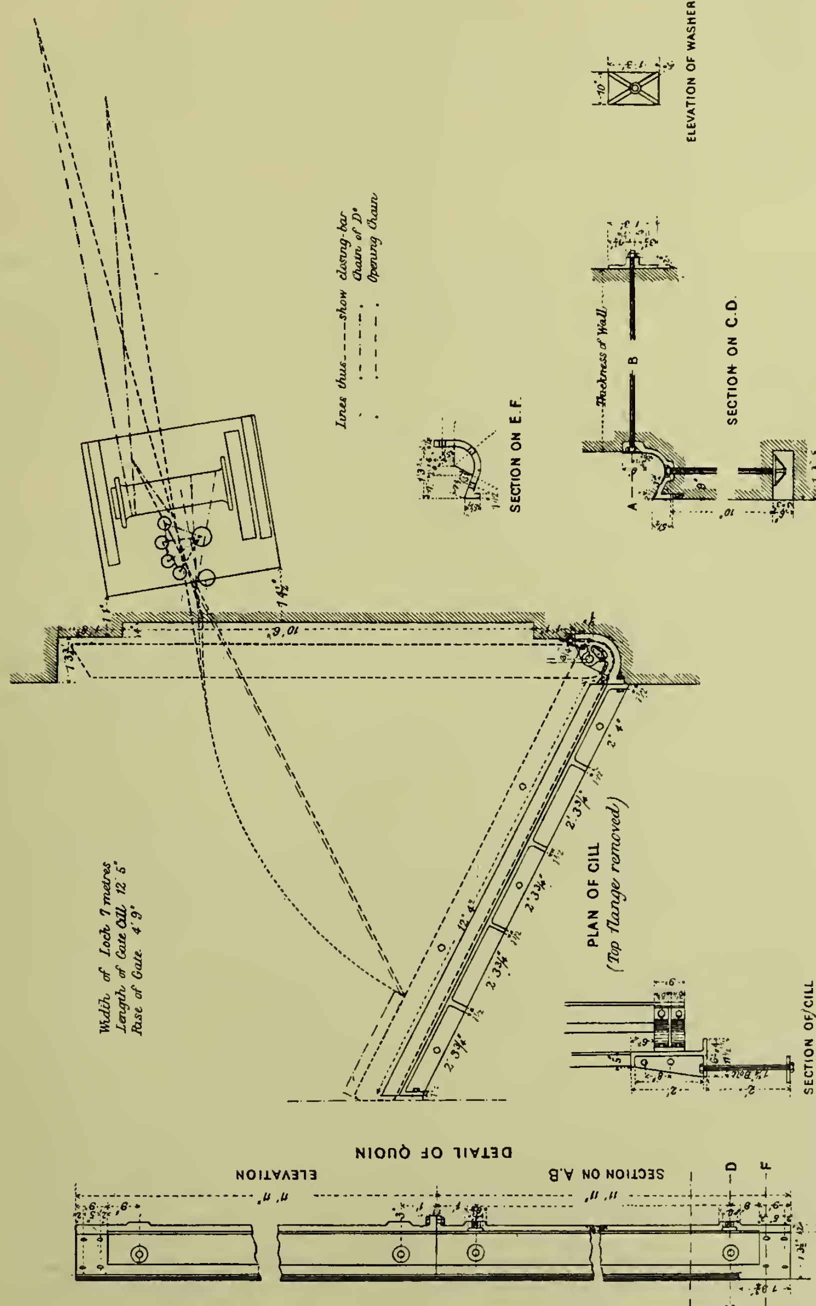


Fig. 134.—Melig Lock. Details of Quoins and Sill. Dimensions in feet and inches. Approx. Scale $\frac{1}{60}$.

to the area of the gate, to allow of a considerable discharge during flood, and thus prevent silt deposits in the locks.

On the main lines of canal the locks should at least be large enough to pass boats of 1000 "ardebs," and therefore have the following dimensions: 30 metres × 8 metres × 2 metres. It has been decided to have locks of 50 metres × 8 metres × 2 metres on the main lines in Lower Egypt. On the Ibrahimia and Ismailia Canals the locks are 35 metres × $8\frac{1}{2}$ × 2 metres. For minor canals where only 250-ardeb boats ply, the locks should be 20 metres × 6 metres × 1·25 metres (a width of 6 metres is necessary to pass boats laden with three bags of cotton laid crossways). In the Berea, where no cotton is carried, but only rice, dates, melons, and fish have to be transported, locks of 20 metres × 4 metres × 1·25 metres will suffice for the traffic. On the Nile itself locks of 50 metres × 12 metres width are necessary for the ordinary steamers. Locks of 15 metres in width alone can pass the double boats of wheat-straw tied together, while widths of 16 metres are needed for the largest new passenger steamers, and have been provided at Assiut and Esna.

Paragraph 17 of CHAPTER I. gives widths of navigable openings at bridges and locks on the Nile.

Plate LXVII. gives details of the Esna barrage lock.

115. **Syphons and cross drainage works** are to-day common in the country. In Upper Egypt, on the syphon canals along the strip of high land bordering the Nile, syphons of the very boldest designs were constructed to carry high-level water from an upper basin series under the next basin canal. These syphons were built of coarse masonry, and of slight section, it having been always assumed that both canals would be full of water at the same time. Since these works act only in flood, this assumption was justified when scarcely any canals had regulating heads, but to-day all that is altered. Fig. 135 gives a plan of the Nizam syphon constructed by Sir William Garstin. Fig. 136 gives a plan of the Sohagia syphon built by Colonel Ross on the Girgawia basin canal. Since 1885 wrought-iron pipes, however, have nearly always been used both for aqueducts and syphons. They are generally constructed of $\frac{1}{4}$-inch sheet iron, butt jointed, and stiffened with L irons at every alternate joint if over 12 feet circumference; and lap jointed if under 12 feet. Since the sheets in the market are 8 feet × 4 feet, or 6 feet × 3 feet, the pipes are always constructed with their circumference some multiple of the length or width, so that there might be no cutting of plates. The pipes are sometimes laid on a bed of concrete, varying from 1 metre to 25 centimetres in thickness according to the quality of the soil, or they are laid on the hard clay soil and well packed round with clay balls. Where the pipes are used as aqueducts, they are generally supported on wooden trestles.

The great advantage of using wrought-iron pipes is that they can easily

be transported; they do not need expensive supervision during construction, and can be put together so rapidly that the cost and trouble of a diversion for the canal during time of construction is avoided. These pipes can be closed at their ends and floated to their destination. By dredging the foundation where they have to be laid, they can be floated over the site and then sunk without shutting the canal head.

Far better than wrought-iron pipes are specially prepared corrugated-

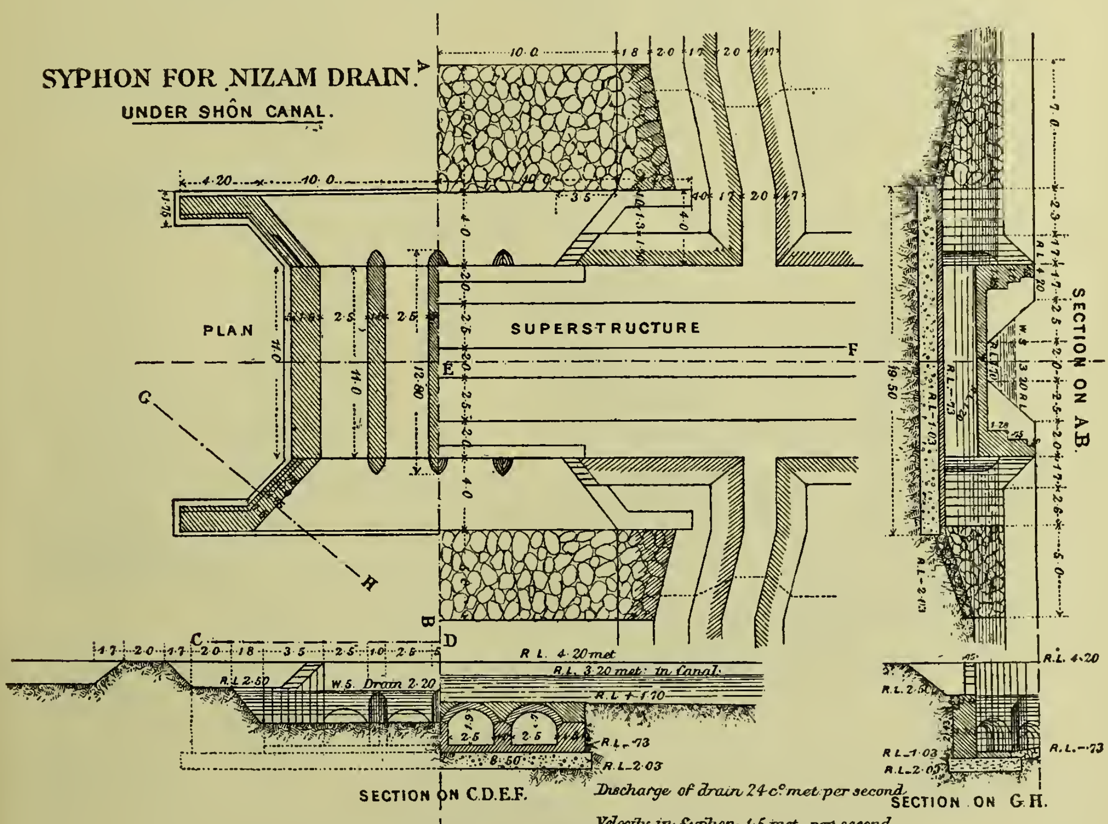


FIG. 135. Scale $\frac{1}{400}$.

iron pipes of the "Acme" or some other brand, which corrode with difficulty, are very strong, easily transported, and easily put together. The manufacturers supply table of discharges and every detail needed, and in all countries where transport is at all difficult they might with advantage replace masonry works. They can be carried in sections on camels and mules, and put up in position and need neither water nor mortar nor anything difficult to obtain. This was said of them in the *Irrigation of Mesopotamia*:—

"Much of the success of the works will depend on the expedition with which

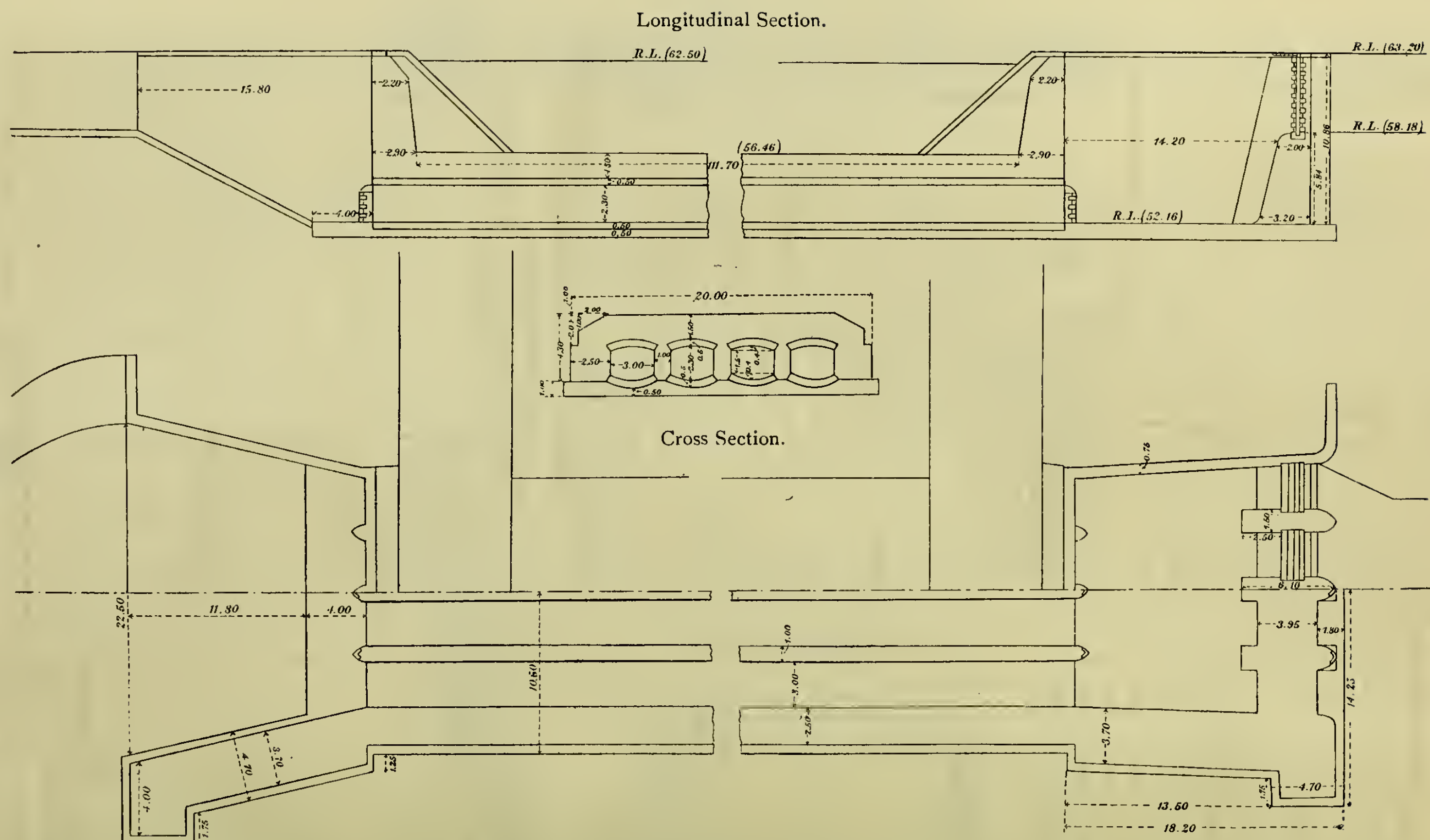
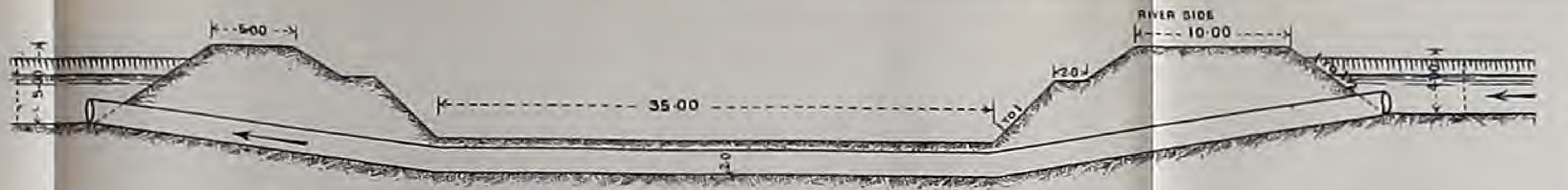


FIG. 136.—Syphon under Sohagia Canal. Approx. Scale $\frac{1}{470}$.

TYPICAL PIPE SYPHONS, CULVERTS AND BRIDGES.

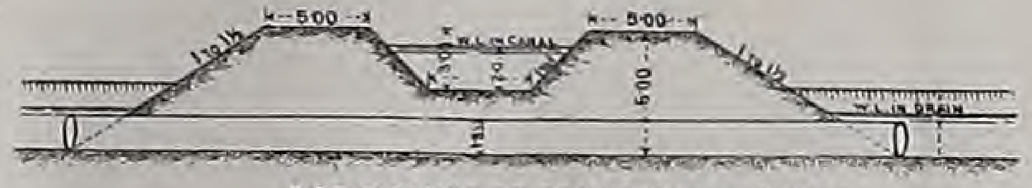


PIPE CROSSINGS FOR WATERCOURSES UNDER RIGHT-TIGRIS AND LEFT-EUPHRATES CANALS.

WIDTH OF CANAL	LENGTH OF PIPE.	DIAMETER OF PIPE 5 FEET=1·52 METRES COST £TQS.	DIAM. OF PIPE 4 FT.=1·22 METRES COST £TQS.	DIAM. OF PIPE 3 FT.=0·91 METRES COST £TQS.
35·00 MTRES.	82·00 METRES	620 £TQS.	460 £TQS.	350 £TQS.
30·00 „	77·00 „	580 „	430 „	330 „
25·00 „	72·00 „	540 „	400 „	310 „
20·00 „	67·00 „	510 „	370 „	290
15·00 „	62·00 „	470 „	330 „	260
10·00	57·00 „	430 „	320 „	240

CORRUGATED ACME PIPES IN POSITION.					
DIAMETER OF PIPE		PRICE PER METRE RUN IN POSITION IN £TQS.	DISCHARGE IN CUBIC METRES PER SEC. FALL 1/100.	WEIGHT IN KILOGRAMMES PER METRE RUN.	THICKNESS IN INCHES.
FEET	METRES				
1·5	0·45	1·8 £TQS.	0·35	23·5	1/16
2·0	0·61	2·5	0·76	34·2	9/128
3·0	0·91	4·2	2·30	55·5	5/64
4·0	1·22	5·5	5·0	100·1	7/64
5·0	1·52	7·5	9·0	124·9	7/64
6·0	1·83	10·0	14·5	190·7	9/64

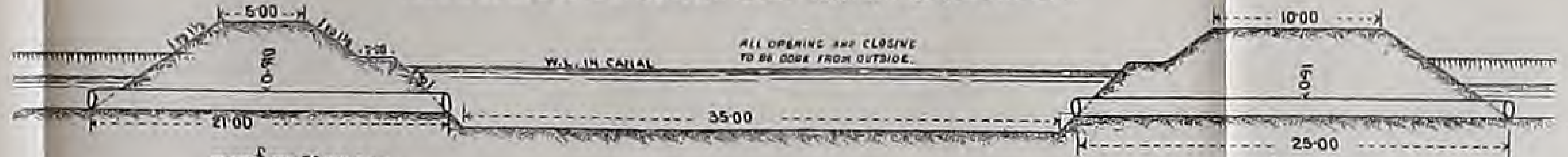
INCLUDES TRANSPORT TO SITE EARTHWORK & FIXING IN POSITION.



PIPE-CROSSING OF DRAINS UNDER CANALS.

ALTERNATIVE TO N[os] 3,4,5 & 6.

LENGTH OF PIPE 40·00 M. DIAMETER 1·83 METRES, COST £TQS. 400 PER PIPE.



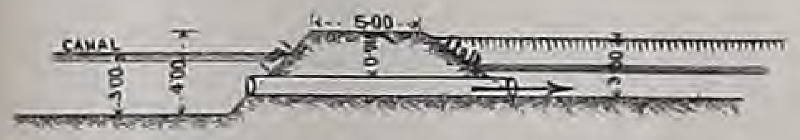
COST £TQS. 90 PER PIPE.

DIAMETER OF PIPE	0·45 METRES	0·61 M.	0·91 M.
COST PER PIPE £TQS.	40 £TQS.	55 £TQS.	90 £TQS.

IRRIGATION PIPES ON LEFT-EUPHRATES OR RIGHT-TIGRIS CANALS.

COST £TQS. 105 PER PIPE

DIAMETER OF PIPE	0·45 M.	0·61 M.	0·91 M.
COST PER PIPE	45 £TQS.	65 £TQS.	105 £TQS.



IRRIGATION PIPE ON ORDINARY CANAL.

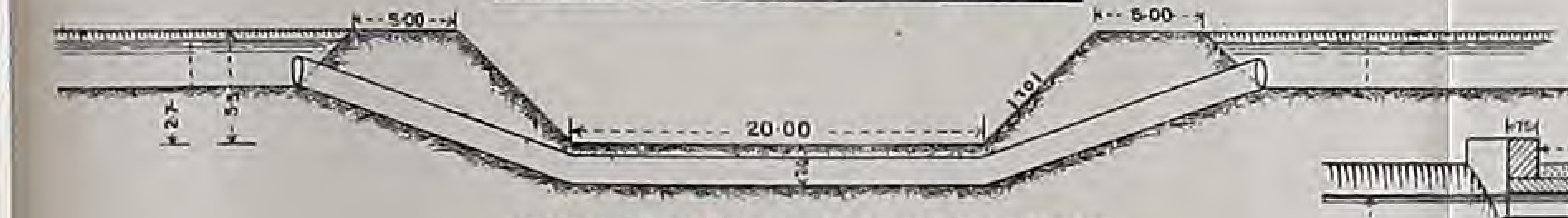
LENGTH OF PIPE 10 TO 15 METRES, DIAM. 3 FEET (0·91 METRES)

LENGTH OF PIPE	DIAM. 0·21 M. COST PER PIPE	DIAM. 0·61 M. COST PER PIPE	DIAM. 0·45 M. COST PER PIPE
10 METRES	42 £TQS.	25 £TQS.	18 £TQS.
11 „	46 „	28 „	20 „
12 „	50 „	30 „	22 „
13 „	55 „	33 „	24 „
14 „	59 „	35 „	26 „
15 „	63 „	58 „	27 „

ORDINARY FLOOD-BANK AND PIPE-CROSSING UNDER FLOOD-BANK.

DIAMETER OF PIPE	0·45 M.	0·61 M.	0·91 M.
COST PER PIPE £TQS.	35 £TQS.	45 £TQS.	80 £TQS.

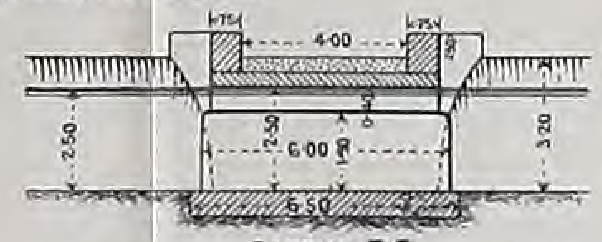
PIPE CROSSINGS OF CANALS UNDER DRAINS



THERE IS 1 PIPE 48·00 M. LONG AND OF 1·52 M. DIAMETER.

SCALE 1/500

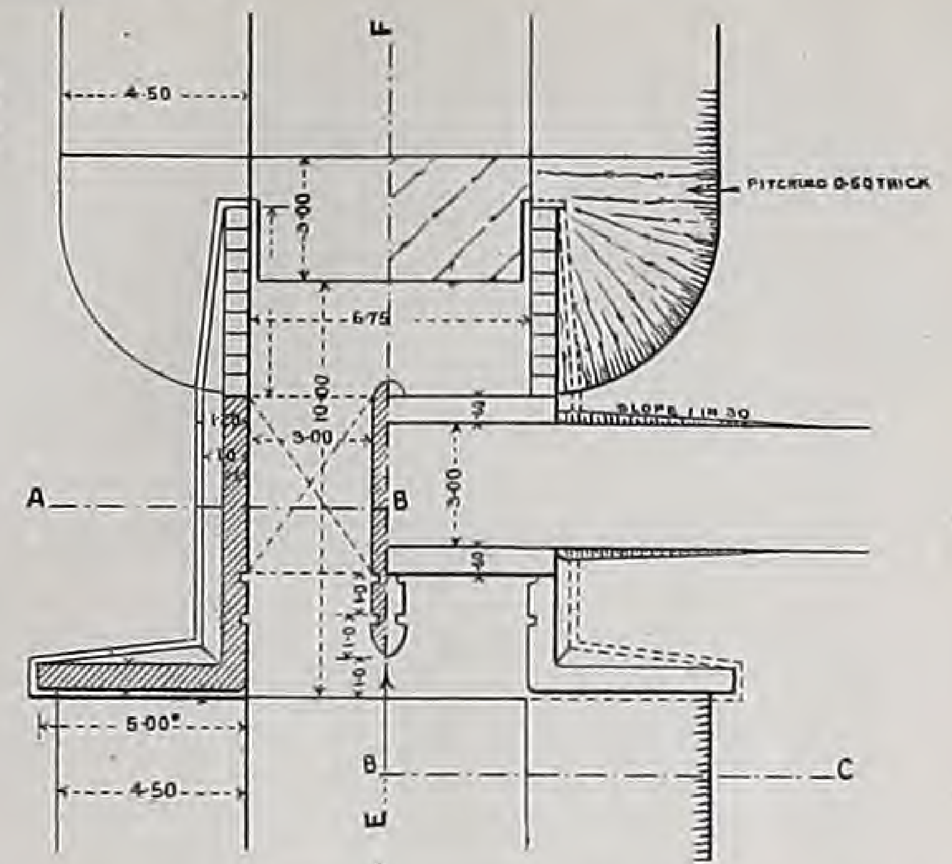
THE FILLING ROUND THE PIPES AND ABOVE THEM SHALL BE DONE WITH WELL WORKED STIFF PUDDLE, FORCED INTO POSITION AND CAREFULLY RAMMED.

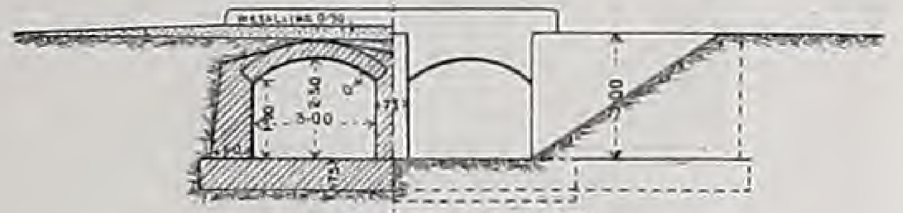


SECTION E.F.

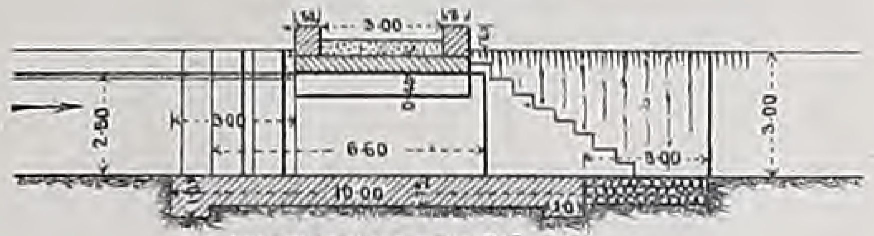
ORDINARY ROAD-BRIDGE ON CANALS.

SCALE 1/250





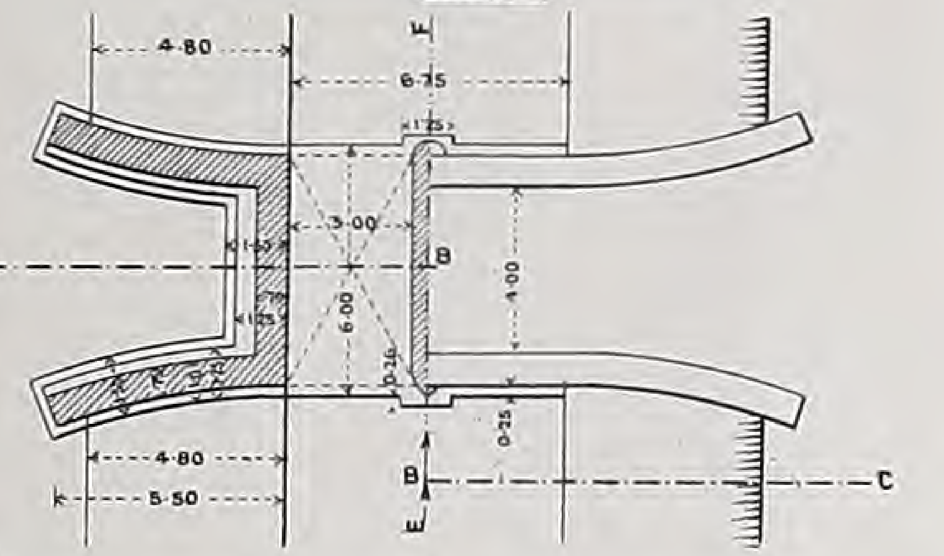
SECTION AND ELEVATION ABC.

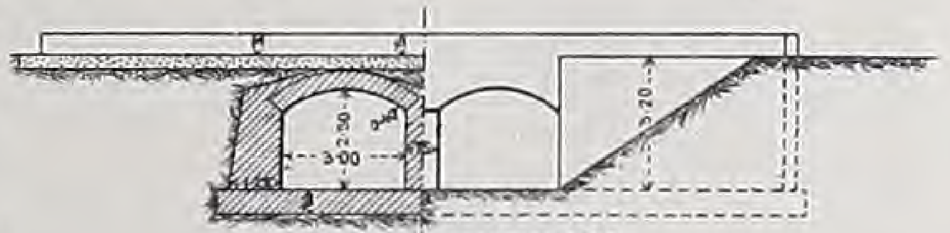


SECTION AND ELEVATION E.F.

ORDINARY REGULATING HEAD ON CANAL.

SCALE 1/250.





SECTION AND ELEVATION A.B.C.

E. & F.N. Spon L[td] London.

they are carried out, and the sooner they are completed the sooner will they be remunerative, and reduce the interest charges. It is on this account, therefore, that I think it will be a real economy to employ metal pipes of the "Acme" class wherever possible in place of masonry works; Portland cement on a large scale for the masonry works; and every kind of steam excavator for the earthwork. Indeed, to these three essentially modern productions will be due in great part the resurrection of this ancient country."

Plate XLVII. gives typical pipe syphons, culverts, and bridges as proposed for Mesopotamia. The country is covered with a dense brushwood, with which all slopes of banks are protected. These slopes so protected stand better when at $\frac{1}{1}$ than at gentler slopes, and it is for this reason that all the batters are at $\frac{1}{1}$.

We now give two selections from the *Irrigation Reports*:—

"*Note of Mr Molesworth on Abu Zabal Syphon.*—This is a pipe syphon composed of $\frac{1}{2}$-inch mild steel plates. The length of the pipe is 85 metres, and the diameter 1·50 metres. See Plate XLVIII.

Owing to the conditions of the locality and the impossibility of drying the Ismailia Canal, it was necessary to place the pipe in position without resorting to the usual practice of diverting the canal.

The method of placing the pipe was by means of dredging a trench to the required depth across the canal, floating the pipe into position, piercing the water-tight doors and sinking into place. The canal banks were then remade over the pipe ends, and operations for getting in the necessary pitching and stone-work to protect the ends of the pipe and hold up the banks begun.

The pipe was sunk in February 1902, and all efforts to excavate and get in the pitching by ordinary means failed, in spite of repeated attempts, the springs proving too strong and the nature of the soil at site being such as to render the excavation in such a limited area well nigh impossible.

In August 1902 all attempts to get in the pitching by ordinary excavation were abandoned, and it was decided to sink masonry wells at either end of the pipe, and, by boring through the walls of these, it was proposed to establish a through communication. These wells were of brickwork in cement up to a reduced level of 10 metres, and, in order to drown out the springs, had to be carried up another 3 metres in temporary masonry before they could be plugged with grout.

The operations of sinking and grouting were successfully carried out, and it only remained to dry the wells and bore through into the pipe. But, on account of the wells not having sunk exactly flush with the pipe ends, spaces were left between these and the backs of the masonry wells. The spaces were as much as 13 centimetres on the upstream and 19 centimetres on the downstream side. Directly holes were pierced through the walls springs started, carrying back through the newly bored holes such quantities of sand and water as to preclude the possibility of enlarging the apertures to the same diameter as that of the pipe.

Various attempts to cut these holes both by divers and other means were made, but proved abortive.

In April 1903 it was decided to abandon the idea of getting at the pipe ends in 'the dry' and by use of divers, and to resort to the method of grouting. For

this purpose, all materials, such as stones, piles, etc., which had been used in the former operations were cleared away from the neighbourhood of the wells, and sand pumps were erected in order to dredge out inverted cones at the backs of the wells with their apices half a metre below the ends of the pipe on the underside. A certain cube was accomplished by this means, but owing to the gravelly nature of the sand, the laborious process of excavating the remainder by means of divers had to be reverted to. However, the excavation was at length accomplished, and everything was got ready for grouting.

To guard against a leakage of cement into the pipe, strong circular wooden doors were lowered by divers and tightly wedged up against the pipe ends by means of wooden wedges against the well walls.

A grout-tight joint was made between the pipe flange and the wooden door by nailing tarred canvas on the door as a fitting strip where the pipe flange would abut.

The holes already broken through the well walls were stuffed with sacking and the wells themselves filled with sand up to a level 1 metre above the top of the pipe.

Divers then scrubbed the face of the masonry all round the pipe lip where the grout would form a joint against the well. This was done with foundry brushes, the bristles of which were shortened to render them stiffer. On all the dirt and slime being cleaned off, rubble stone was lowered and packed round the grout pipes which had been placed on each side of the end of the syphon pipe. The rubble stone was built to a level equal to one-third the way up the vertical diameter of the syphon pipe, thus filling up the lower part of the dredged cone. This layer was then grouted up, the cement used being 'Casale Monferrato,' and a solid block of masonry was obtained under the end of the pipe syphon and against the wall back.

In order to economise grout, wooden boxes were constructed so as to overlap the well sides and saddle over the pipe; their position will be better understood from the drawing. They were fixed by iron tie bolts which, on being screwed up, gripped the overlapping ends of the boxes against the well walls. After the first layer of grout had been cleaned, these boxes were filled with rubble stone by the divers to a height of half a metre above the large pipe. On this being done, the boxes were covered with sacking and a talus of sand was formed round the sides of the box by passing the sand through a pipe manipulated as a chute from above. This was done to prevent leakage of cement under and through the boxes.

The boxes were then grouted up through the same pipes as were used for the lower layer.

The masonry blocks thus formed were allowed two days in which to set, and the wells were then unwatered, cleared of sand, and the sacking removed from the holes in the well walls.

Everything was found to be quite watertight, and the enlarging of the holes to the same diameter as the inside of the syphon pipe was proceeded with.

This was accomplished and the wooded doors cut through, and a perfectly watertight joint was found to exist round the pipe end and against the well back.

Thus for an outlay comparatively small, as compared with the expense incurred in the endeavours to complete the syphon by other means, the work was successfully finished."

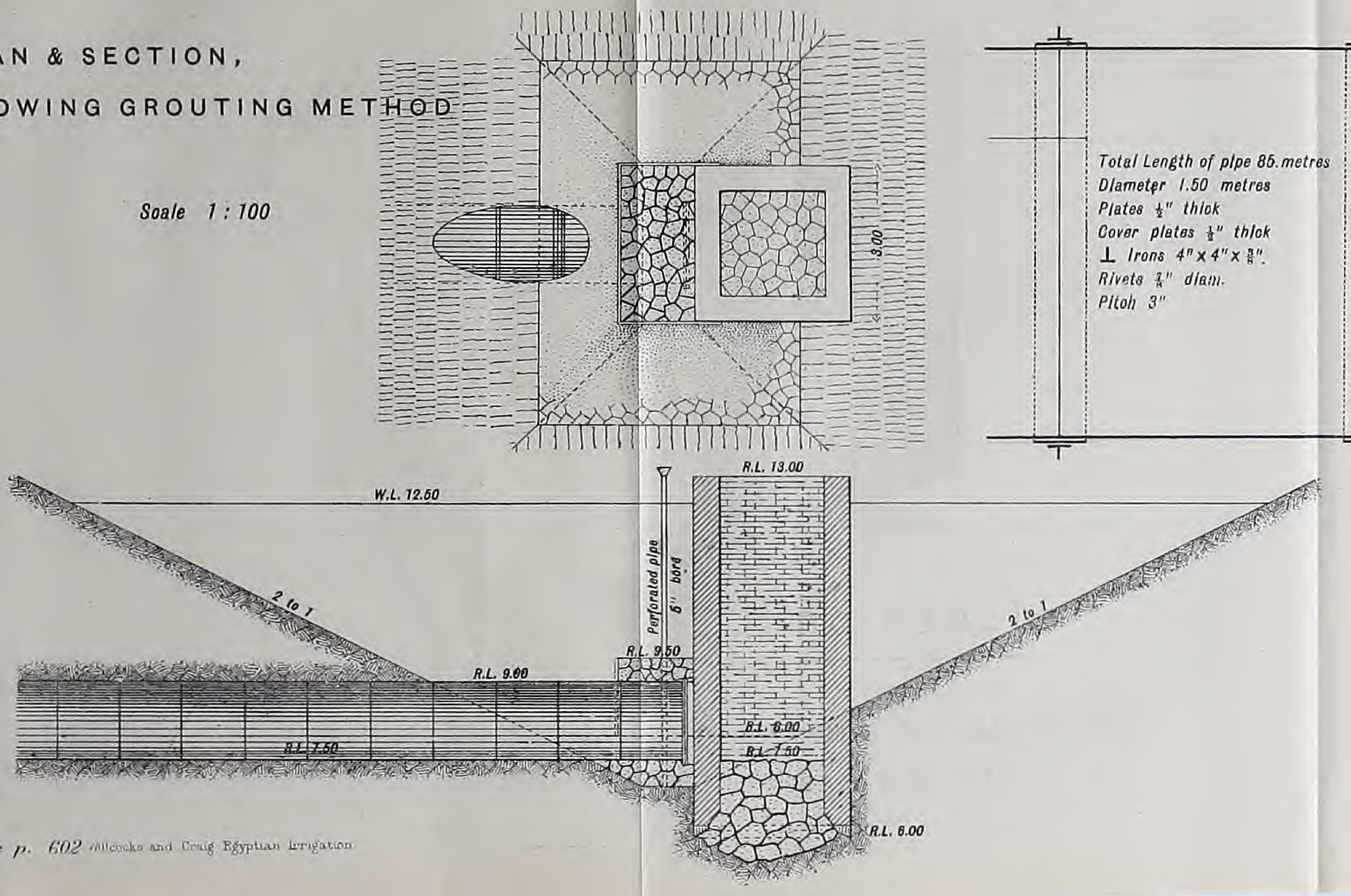
LONGITUDINAL SECTION OF SIPHON

Scale 1 : 250

PLAN & SECTION,

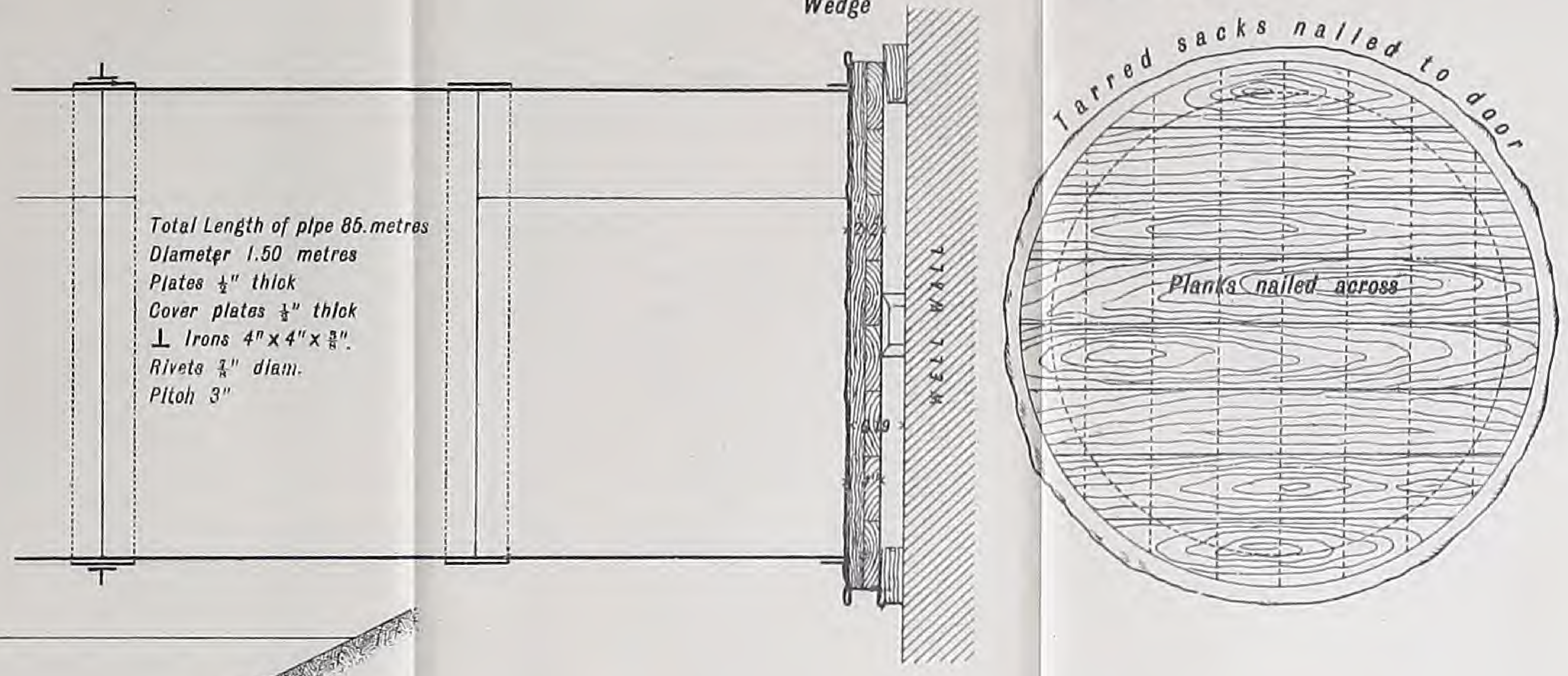
SHOWING GROUTING METHOD

Scale 1 : 100



DETAILS OF TIGHTLY WEDGED WOODEN DOOR

Scale 1 : 20



BILBÊS DRAIN

SIPHON UNDER ISMAILIA CANAL

AT ABU-ZABAL

"*Note on Pipe Syphon under Ismailia Canal at Kilo* 45.—The Ismailia Canal along this reach runs in high embankment, high water level being from R.L. 12·70 to 12·50; ground level on the left from R.L. 9·0 to R.L. 10·50, and on the right from R.L. 11·0 to 12·20. At the site selected the ground level on the left was 10·30, and on the right 11·0. Owing to the sandy nature of the soil and the high water level, it would have been very difficult and costly to make a diversion of the Ismailia Canal, for the construction of the syphon in the dry, so it was decided to construct it in a similar manner to that by which the Mansuria and Abu Zabal syphons were done, namely by dredging out a channel and floating a pipe into place. In order to maintain the type sections of the canal a pipe 89 metres long was required and of 10 feet circumference, or 0·84 metres internal diameter.

Fig. 137 gives a cross section of the canal, and fig. 138 shows in plan the supplementary banks constructed, and general arrangements to enable the pipe to be floated into place. The pipe was constructed of mild steel half-inch plates, 4 feet wide, with one longitudinal lap-joint. Every second transversal joint consisted of a 12-inch × ½-inch cover plate stiffened by a 6-inch × 3 inch × ½-inch T-iron. The intermediate joints were formed by 8-inch × ½-inch cover plates. The pipe was built in the workshops and transported to site in 8-foot lengths, riveted up on sleepers, and laid on a flat platform cut in the berm of the canal 250 metres upstream of the site. Owing to the high canal level and the great length of the pipe, diversion banks were required on each side, in order to give room to float and swing the pipe into place, for which purpose also platforms at R.L. 11·0 were excavated.

All earthworks to R.L. 10·50 were done by hand. The channel into which the pipe was eventually sunk was excavated by dredger below R.L. 10·50, the bed R.L. required for the pipe being 7·86. When the channel was dredged to the required depth by the grab dredger, the bed was levelled off with the pump dredger and arrangements were made to float the pipe into place.

The pipe was riveted together on a platform of sleepers upstream of the excavations. It was caulked and given three coats of hot tar inside and out. The ends were closed with strong wooden doors, each of which was fitted with a 6-inch and a 3-inch pipe, the former to admit water and the latter to let out air. When completely fitted, a pressure of one atmosphere, by means of a hand pump, was applied inside to test the joints; the leakage was insignificant.

The following figures may be of interest. Length of pipe, 89·0 metres; internal diameter, 0·84 metre. Actual weight of pipe, 32·932 tons. Cube of water displaced by pipe, 4·224. Weight of pipe in water, 28·708.

Previous to floating the pipe the piles A and B were driven 3·0 metres into ground —the former to serve as a pivot round which the pipe should turn, the latter to serve as a stop. The boats, braced firmly together by means of wooden platforms and fitted with winches, were placed in pairs on either side, in order to support the pipe, when sinking, and lower it slowly. On the day fixed for sinking the pipe, 9th January 1906, the water in the Ismailia Canal, which had been lowered, was raised to R.L. 12·10 to enable the pipe to float over the platform at R.L. 11·0. When all was ready the pipe was lowered in the water and floated to site. It pivoted round pile A and came to exact position without any trouble. The boats were then floated along the side and the winches attached at a quarter distance from either end,

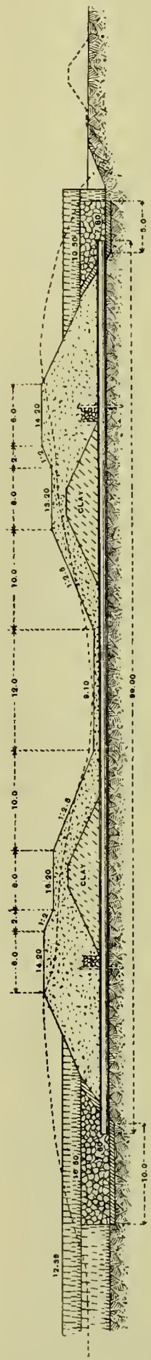


FIG. 137.—Syphon under Ismailia Canal. Longitudinal Section.

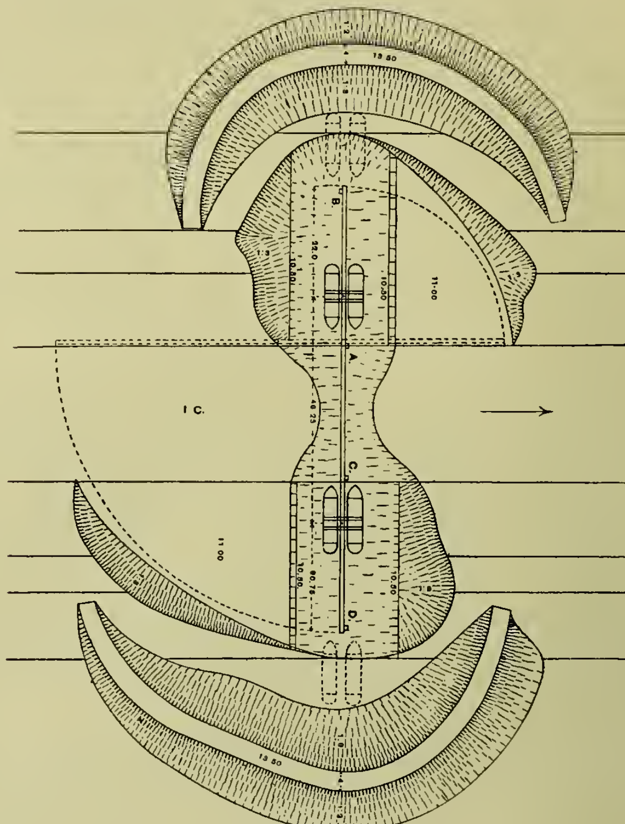


FIG. 138.—Syphon under Ismailia Canal. Plan.

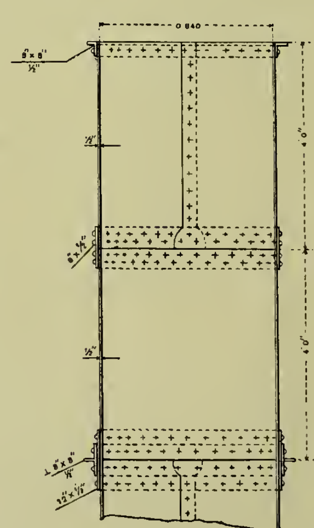
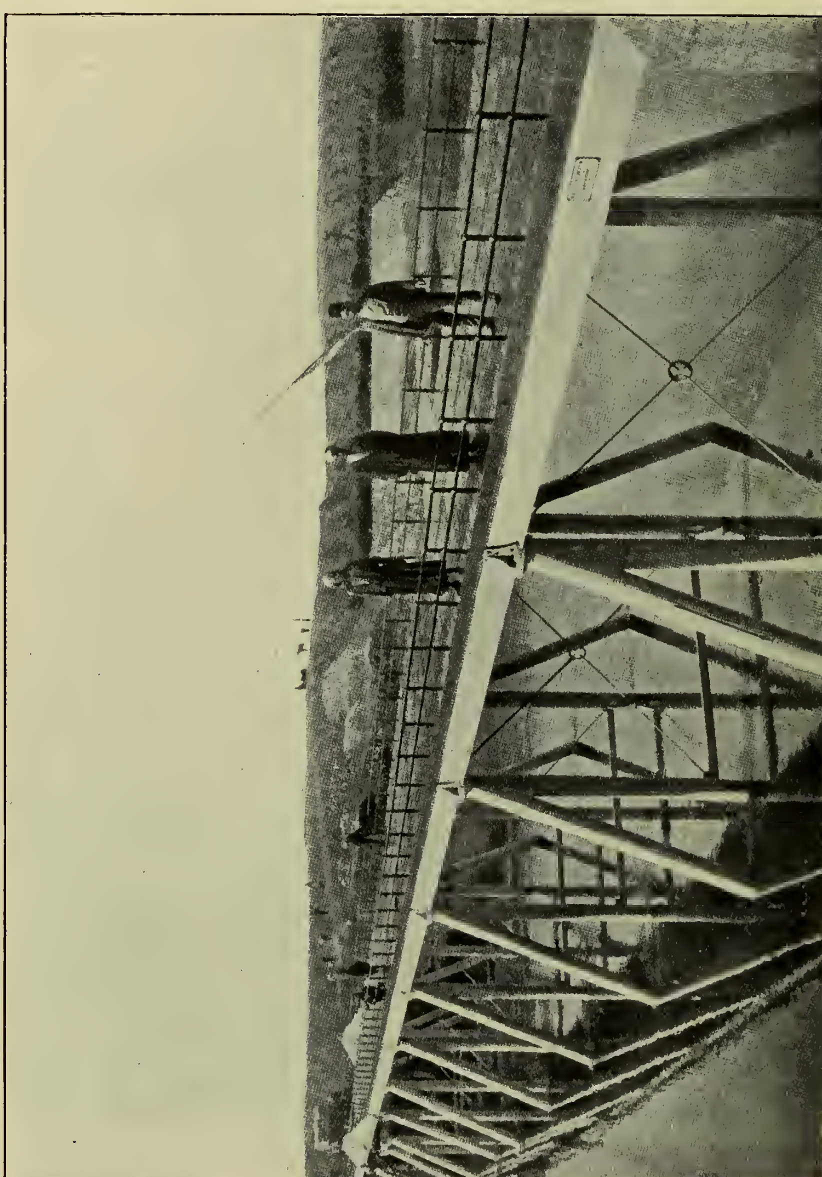


FIG. 139.—Syphon under Ismailia Canal. Details of Pipe.

Construction of Pipe Syphon under Ismailia Canal.

Road Bridge, Kilibia Canal.

PLATE L.



Manfalut Swing Bridge, 96 metres long, 5·metre roadway.

To face page 605.

with the object that each pair of boats should support half the weight of the pipe. The boats were securely anchored up and down stream, and the water and the air pipes opened. The pipe then began to settle down gradually, but owing to the difficulty of directing the slacking of the winches exactly equally, and also to the fact that the ropes by which the winches lowered the pipe caused it to revolve in the water, there was considerable oscillation backwards and forwards of the water in the pipe. When about half submerged, owing to the oscillation, a cushion of air was impounded in the centre of the pipe, which caused it to rise and the ends to sink. As the water continued to enter, the stress on the pipe increased, and it was evident from the cracking and creaking noise that the joints were severely strained. As the quantity of water already in the pipe was just sufficient to overcome its flotation, the winches were slacked off and the pipe settled down very slowly to the bottom. It took about ten minutes from the time it was submerged till it rested on the bottom. At time of letting go the centre of the pipe was about ·50 metre above water, the ends about 1·0 metre below, and the supported parts at water level, showing a total bend of 1·50. As the pipe sank, bubbles of air came from nearly all the joints, showing that they were all strained more or less, and there was fear of the pipe leaking. As, however, the bubbling continued all day, this proved that there was no rupture and that the leakage was very slight, for had there been any rupture the air would have escaped at once and bubbling would have ceased. The reason that the air did not escape through the air pipes was that, when the pipe was let go, these air pipes, which had got twisted round, got buried in the mud in the bed of the channel. It was therefore decided to continue the work without further examination of the pipe.

The water in the canal was lowered as much as possible, and clay sudds thrown across the pipe. A 6-inch centrifugal pump was erected on the downstream side of the pipe, and the excavation outside the sudds was pumped dry. On removing the doors from the end of a pipe a thorough examination of it inside was made, when it was found that there was no leakage whatever in any of the joints. The works being so far satisfactory, the stone pitching at each end of the pipe was then built and the Ismailia Canal was restored to full section. The original allotment for the works was £2000, preliminary estimate was £1800, and the actual cost was £2290."

Plate XLIX. shows the boats supporting the floating pipe.

116. **Irrigation Surveys and Discharges.**—The following quotation from *Irrigation in Mesopotamia* explains how the surveys of a new country similar to Egypt were carried out and the discharges taken :—

"The following report on the methods employed to obtain the maps and levels of the country was written by Mr B. T. Watts, who directed the work.

In deciding upon the method in which the surveys and levels should be carried out the following facts had to be taken in count :—

(1) There were no levels at all of the country;

(2) Except Collingwood and Selby's survey of part of the Delta and the 'Comet' plan of the Tigris there were no reliable maps of the country;

(3) The area of the land capable of being irrigated, from which the most suitable tracts were to be selected, was very extensive;

(4) The work had to be done as quickly as possible.

Taking the above facts into consideration, it was decided that triangulation was superfluous, and that plane table traverses with the aid of the tacheometer and magnetic needle would suffice. We should thus not have perfect maps of Mesopotamia, but a good workable idea of the nature of the country sufficient to allow projects for the irrigation of the country to be prepared.

There were four survey parties, each of which consisted of one surveyor and two levellers. The levellers worked side by side using 14-inch levels (Cooke & Son's) fitted with stadia hairs and compass.

Good results were obtained by plotting (Chambers' traverse tables) each day's level traverse from the level compass readings, and then transferring it to the map, the surveyor and levellers starting and finishing on the same points; by this method it was found possible to cover a much larger area, as the plane table did not necessarily follow the same line as the levels; the difference between the two lines generally worked out at about 1 in 200.

The first work undertaken was to connect Bagdad with the sea by a line of levels, and the mean sea-level found on two consecutive days at the Khor Abdallah was taken as the zero for all future levelling.

The length of sights taken when fixing the preliminary bench-marks varied between 100 and 200 metres according to the time of day.

The numerous checks on these bench-marks, except in a few isolated cases, have been well within the limits of levelling for irrigation purposes.

The scale of all field maps was $\frac{1}{50,000}$, this being found to give a good idea of the country traversed.

Traverses were run down the two rivers (Tigris and Euphrates) and down the centre of the country, and were tied up by numerous cross traverses between the two rivers. These lines have formed the bases for compiling the $\frac{1}{50,000}$ scale map.

The error in length of the different traverses generally worked out at about 1 in 300.

Subsoil water was recorded wherever it was found.

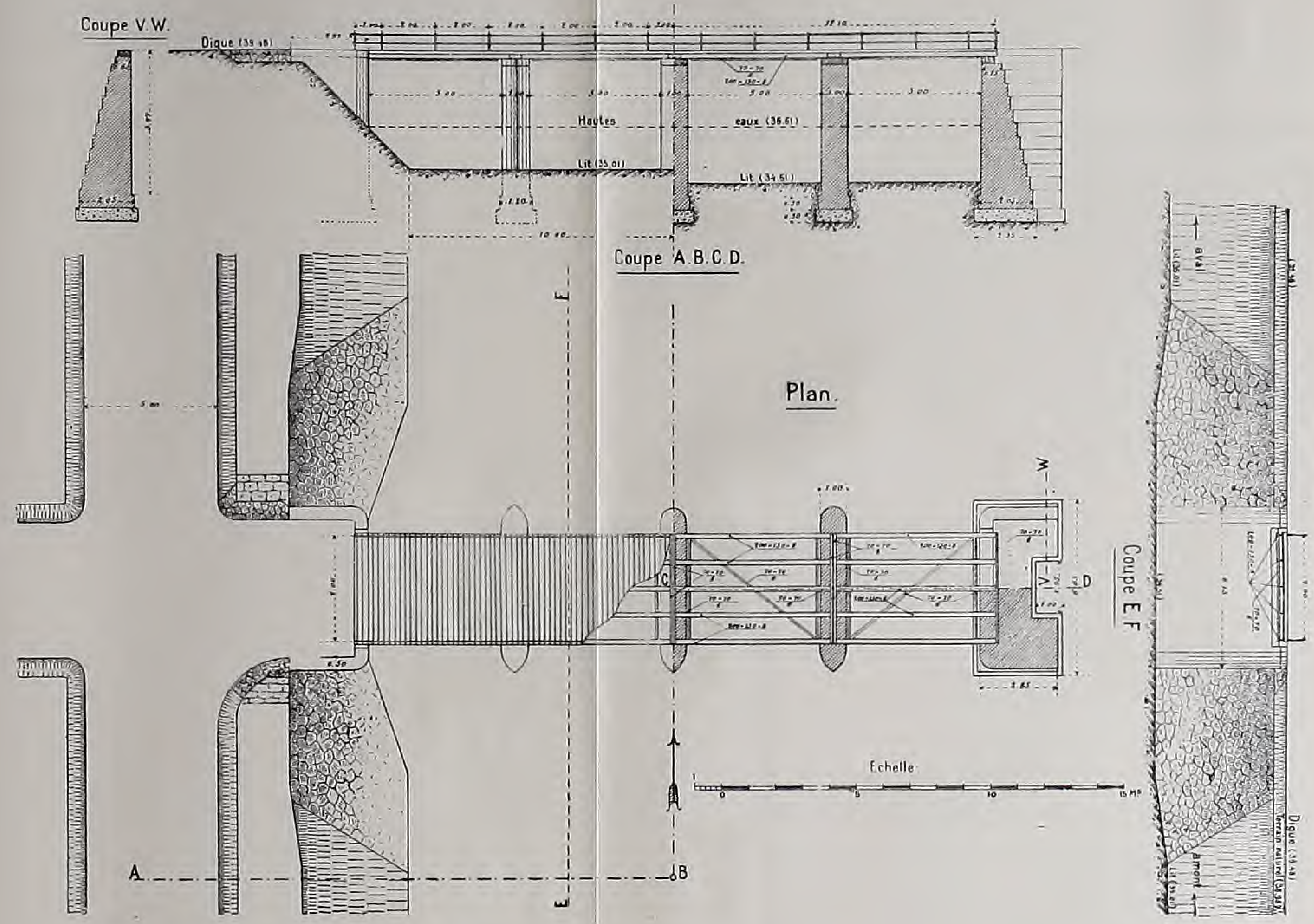
The sections and discharges of the rivers were found to be a work of some difficulty, as proper boats could only be obtained at Bagdad, and "gooffas," circular coracles peculiar to Mesopotamia, could only be obtained in a very few places outside of the towns, and then, from their peculiar shape and method of propulsion, made the work a slow and tedious affair.

The discharges were taken with surface floats over some fixed distance, the positions of these floats or of the boat when taking the soundings, etc., were read off by the tacheometer on shore from a staff held in the boat or "gooffa." Harlacher's method for calculating discharges was invariably employed. For taking discharges of the Tigris at Bagdad we had the loan of the motor launch of the British resident.

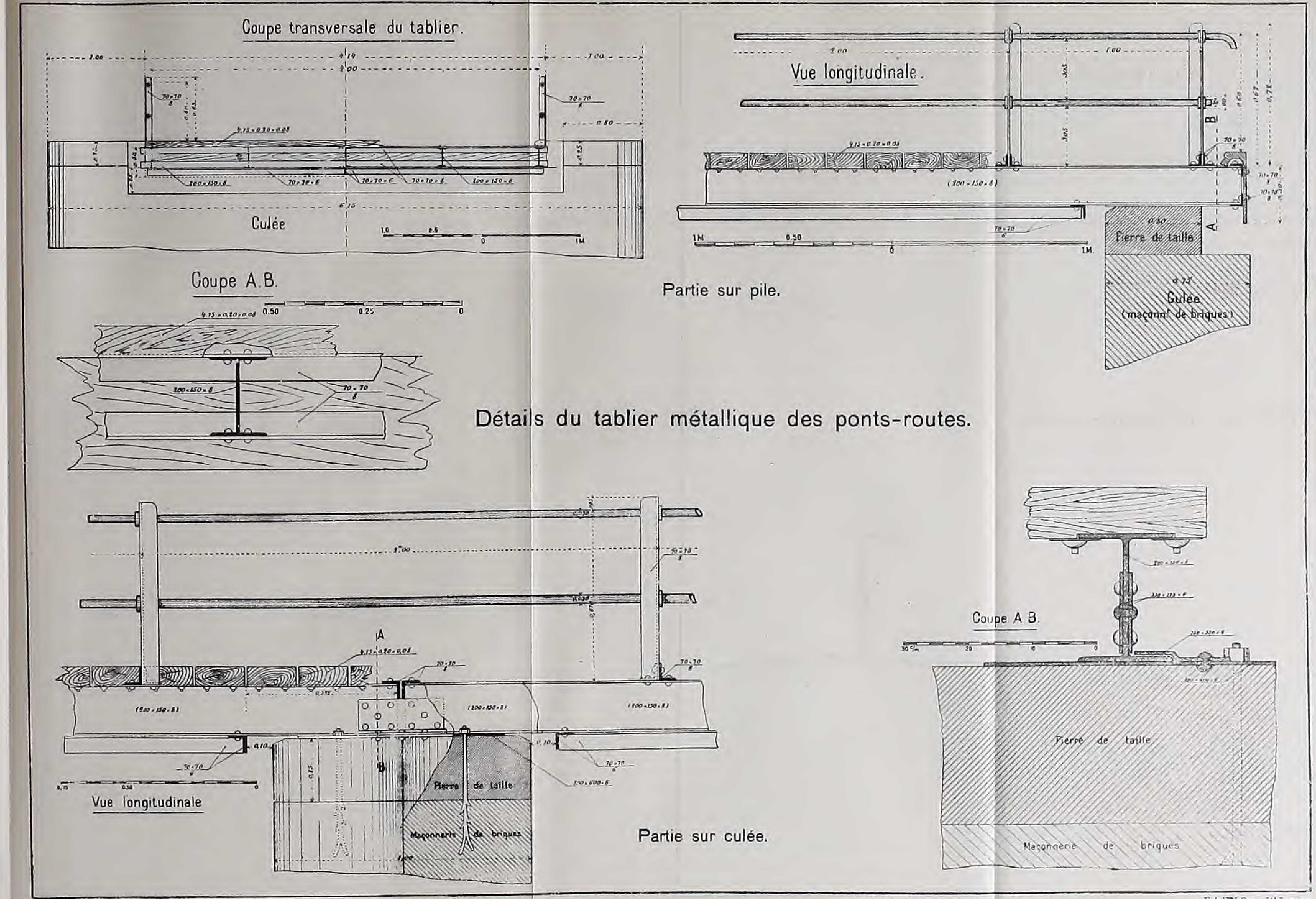
Though the authorities rendered us every aid in their power and supplied police to accompany every party, there were difficulties peculiar to the country, among which may be mentioned: (1) the absence of water in the interior; (2) the large marshes which form close up to the river in flood time, greatly impeding the movements of the baggage animals; and (3) the intertribal troubles which in a few places prevented the work from being carried out.

Type de pont-route à tablier metallique.

Pont-route sur le drain Muhit (Hod-Tahawi).



To face p. 606. Willcocks and Craig Egyptian Irrigation. E. & F. N. Spon Ltd London.



Détails du tablier métallique des ponts-routes.

E. & F.N. Spon Ltd London

With respect to the difficulties encountered owing to the absence of water, it may be stated that Egyptian army fantasses, or metal water cans, were found invaluable."

The discharges of the Nile are generally taken by current meters.

117. **Bridges.**—Bridges in Egypt are generally made of iron girders or rails resting on masonry abutments with a wooden platform. Plates LI. and LII. give details of such bridges as constructed on the basin conversion works. They were designed by H.E. Ismail Pasha Sirry and are taken

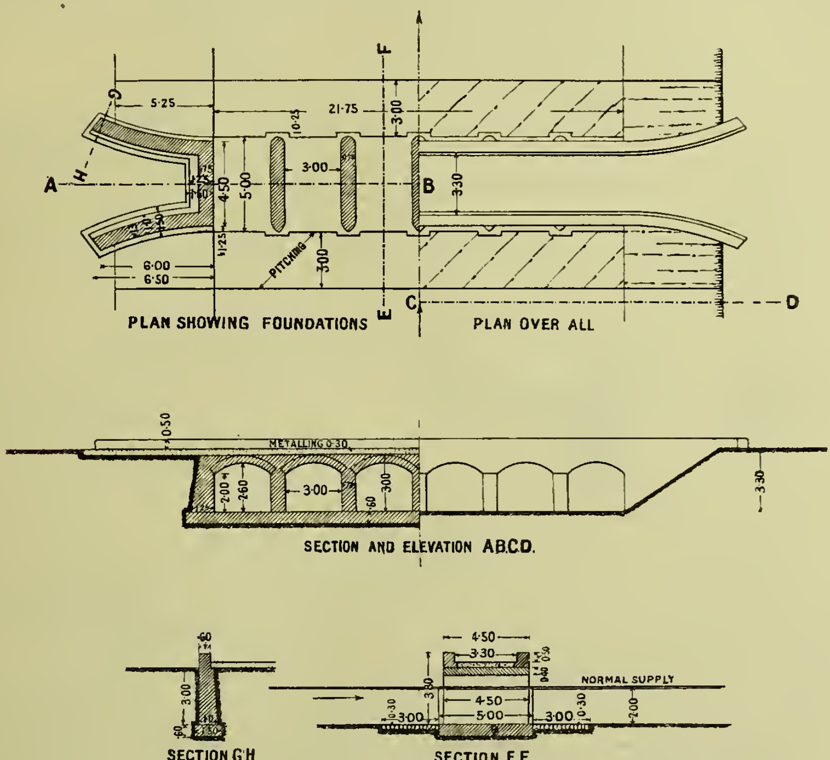


FIG. 140.—Ordinary Road Bridge for Akkar Kuf Drain. Approx. Scale $\frac{1}{350}$.

from M. Edmond Béchara's book. The main canals have screw piles supporting girders, and above them wooden platforms. Some are formed entirely of rails. Plates XLIX. and L. give a good idea of these works.

Fig. 140 gives the type of masonry bridge proposed for Mesopotamia and taken from *Irrigation in Mesopotamia.*

118. **Banks.**—The Nile is a deltaic river freely overflowing its banks in high flood, and consequently the existence of the country depends upon its banks, which were the first works to be executed in the valley. However important they were in old basin days, they are of far more serious import in our day of perennial irrigation. Paragraph 101 of CHAPTER IX. gives the cross sections of the Nile banks, while paragraph 102 gives plans of the

irrigation culverts which are taken through them, and paragraph 103 of the spurs and protective works.

The banks surrounding the basins are of great importance and are maintained to type sections. We quote from page 24 of Sir Hanbury Brown's *Irrigation* :—

"The principal banks have a width of 5 metres and slopes of 2 base to 1 rise. The crest is 1·25 metres above high water-level in the basin. The slopes exposed to wave action are protected by dry rubble pitching or a dwarf masonry wall. Banks exposed to water on one side only have the unexposed slope made $1\frac{1}{2}$ to 1. The width of the less important banks varies from 3 to 4 metres."

The following quotation is from the *Irrigation Reports*:—

"Some years ago dwarf walls were made to protect the bank at several places, but recently stone pitching only has been used. This year 1300 lineal metres of wall on Banawit basin cross bank and Kawamil longitudinal bank were constructed with satisfactory results.

The walls are built of native burnt bricks, mud and lime mortar, and plastered

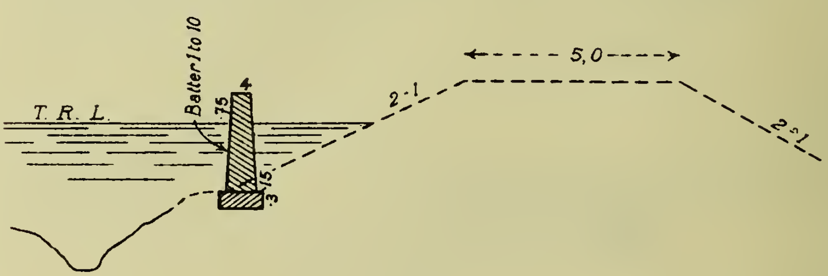


FIG. 141.

with homra and lime. (This is the same material as that of which the old walls are completed that have stood well.)

The type section of the present proposed wall is given in fig. 141, the average section of which may be taken at 1·40 cubic metres per metre run, costing £·70."

119. **Discharges through Small Pipes.**—The following report by Mr H. Hindmarsh is from the *Irrigation Reports* :—

"By order of the Inspector-General of Irrigation for Upper Egypt, a series of experiments in the discharge of water through pipes has been carried out.

The object was to ascertain what, if any, modification must be made in the standard formulæ obtained by calculation and by observations made under the ideal conditions of the laboratory, in order that these formulæ might be accurately applied to the case of Nile water discharged through short lengths of iron pipe, similar to those used as irrigation outlets from public canals.

For this purpose the pipes tested were taken at random from a large consignment of C.I. pipes with spigot and socket joints destined to be used as outlets; they were fixed as nearly as possible in exactly similar positions to those they would occupy in a canal bank, and no mathematical formulæ of any kind were used in working out the result of the observations.

The results obtained are shown in the following table:—

TABLE 226.—DISCHARGE OF C.I. PIPES WITH AFFLUX OF 25 CENTIMETRES.

Diameter		Sectional Area		Discharge in cubic metres per second.	
in inches.	in centimetres.	in square inches.	in square centimetres.	5·5 metres long.	11 metres long.
4	10·2	12·6	81·7	·0113	·0090
5	12·7	19·6	126·7	·0193	...
6	15·2	28·3	181·5	·0287	·0251
7	17·8	38·5	248·8	·0409	...
8	20·3	50·3	323·6	·0544	·0475
9	22·9	63·7	412	·0720	...
10	25·4	78·6	507	·0943	·0829"

120. **Canals and Drains.**—Table 227 gives typical canals as they were in 1888, from the second edition.

Fig. 142 gives the section of the New Giza Canal, and has been sent by Mr P. R. Boxwell.

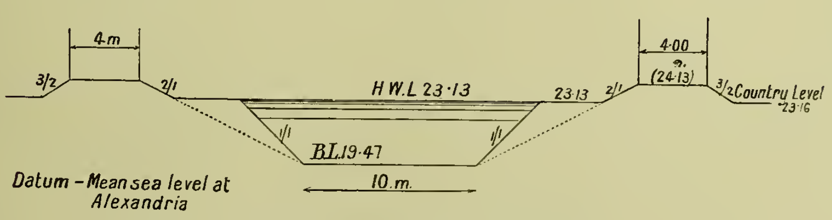


FIG. 142.—Cross Section of Giza Canal.

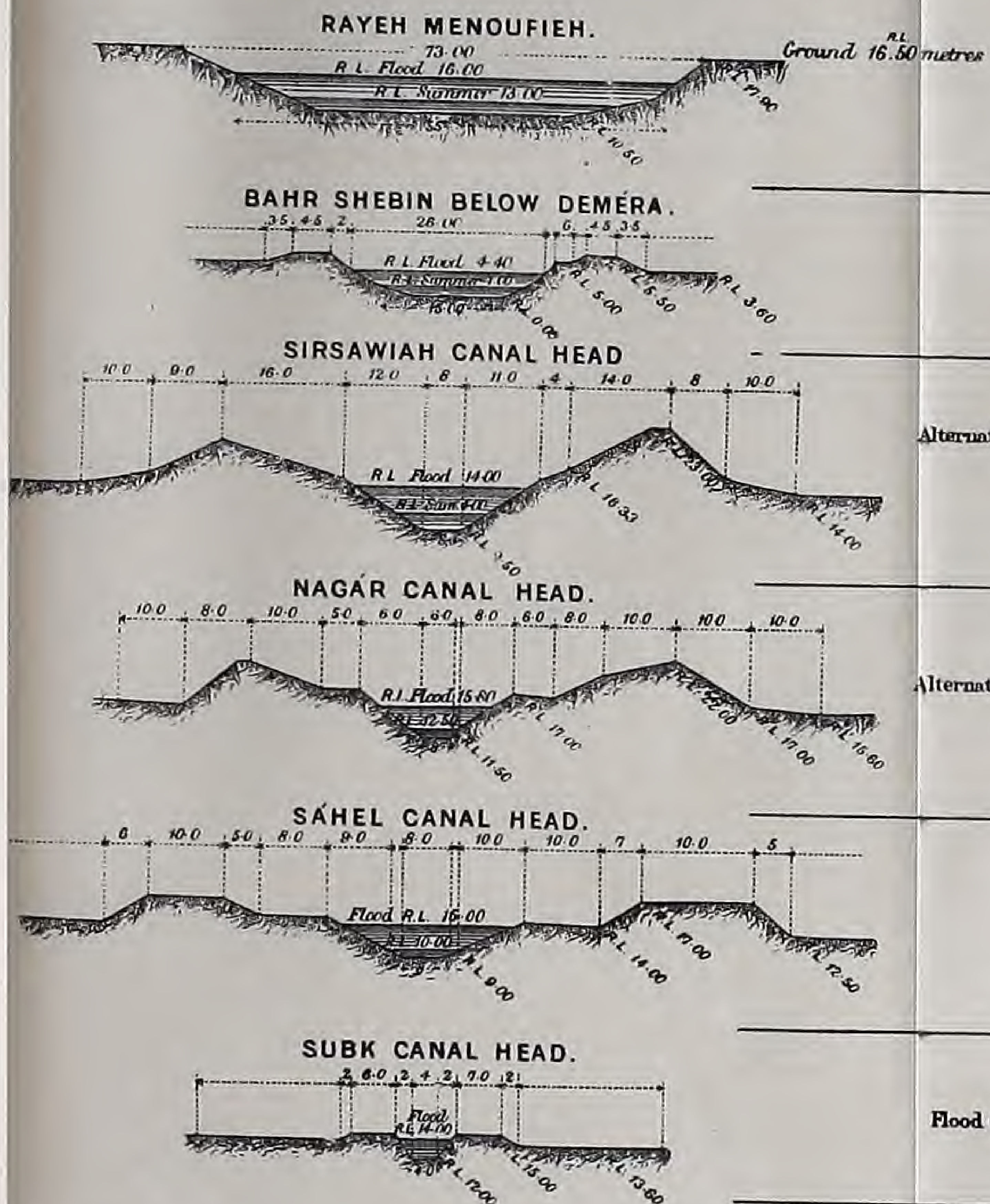
We tabulate here the numbers of the pages on which reference is made to *Maintenance* (see page 620):—

Basin banks, 319, 365, 608.
Basin irrigation, 337, 346.
Perennial irrigation, 427.
Canals, 319, 320, 383, 421, 620.
Drains, 469, 471, 473, 624.
Regulators, 322, 566, 644, 653, 654.
Nile banks, 523, 538.
Nile culverts, 539, 540, 542.
Assiut and Esna Barrages, 663, 664, 673, 674.
Aswan Dam, 727, 748.
Budget, 810.

TABLE 227.—MAIN CANALS, MENUFIA AND GHARBIA (1888).

Name of Canal.	Length in kilometres.	Bed Width in metres.		Depth of Water.			Slope in Flood.	Velocity in Flood.	Discharge, cubic metres per second.			Remarks.
		Head.	Tail.	Flood.	Winter.	Summer.			Flood.	Width.	Summer.	
Rayah Menufia	23	55	55	6·5	4·5	3·5	1/15,000	·90	420	160	120	Navigable.
Bahr Shebín	186	50	35	6·5	4·5	3·0	1/15,000	·90	270	92	64	Navigable between regulators.
Bahr Bagur	96	25	25	5·0	2·5	2·0	1/19,000	·80	64	29	20	,,
Nagár	27	6	6	4 0	1·0	1·0	1/22,000	·45	11	2·5	2·5	Silts; being provided with extra escapes.
Nenaia	39	6	6	4·0	2·0	1·0	1/14,500	·65	18	9	4·5	
Sirsâwia	85	8	3	4·0	1·5	1·0	1/16,000	·45	20	7	4	Silts slightly.
Atf	59	10	6	4·5	1·5	1·0	1/20,900	·50	23	8	4	
Khadrawia	35	10	6	4·5	1·5	1·0	1/22,000	·50	23	8	4	Silts occasionally.
Sahel	141	8	8	4·0	1·5	1·0	1/14,000	·50	17	6	3	
Séf	62	8	6	4·0	1·5	1·0	1/20,000	·50	17	8	4	
Batanunia	51	10	6	4·5	1·5	1·0	,,	·50	29	12	5	
Kâsad	96	10	8	5·0	3·0	2·0	,,	·70	41	23	12	Navigable between regulators.
Gafaria	70	10	8	3·0	2·0	1·0	1/22,000	·55	14	9	7	
Malha	87	30	60	3·0	2·0	1·0	1/20,000	·65	41	21	5	Navigable in flood and winter.
Tíra	70	30	4	3·0	2·0	1·0	1/12,000	·70	46	12	4	,,
Belkâs	28	15	8	3·0	2·0	1·0	1/18,000	·65	23	5	5	,,
Kuddâba	67	7	4	4·5	3·5	3·3	1/16,600	·65	18	7	6	
Kôtoni	50	10	8	4·0	3·2	3·0	1/12,000	·65	18	9	7	
Saldi	38	30	15	2·5	2·0	1·0	1/30,000	·40	41	6	3	Navigable in flood and winter.

TYPE SECTIONS OF EGYPTIAN CANALS (1888)



DETAILS OF DISCHARGES.

	Season	Bed Width (mean)	Area of Cross Section in Sq. metres	Slope	Mean Velocity metres p. sec.	Discharge in C. metres per second.	
	Flood	55·0	340·00	1/20,000	.90	320	
	Summ.r	55·0	160·00	1/12,000	.70	120	
	Flood	22·00	90·00	1/15,000	.70	60	
	Summ.r	22·0	30·00	1/100,000	.10	2	
Alternative weeks	Flood	8·0	60·00	1/21,000	.50	30	
	Flood	8·0	60·00	1/12,000	.65	40	
	Summ.r	8·0	10·00	1/12,000	.33	3	
Alternative weeks	Flood	6·0	40·00	1/27,000	.45	18	
	Flood	6·0	40·00	1/14,000	.60	24	
	Summ.r	6·0	10·00	1/12,000	.33	3	
	Flood	8·0	60·00	1/26,000	.50	29	
	Summ.r	8·0	10·00	1/12,000	.33	3	
Flood Canal	Flood	4·0	11·00	1/20,000	.30	3	

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Figs. 143 to 147 give cross sections of the main canals in the Second Circle of Irrigation, and have been sent by Abdalla Bey Wahby.

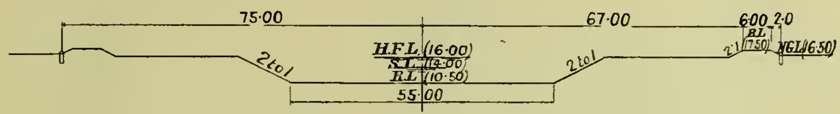


FIG. 143.—Rayah Menufia, Section below Head.

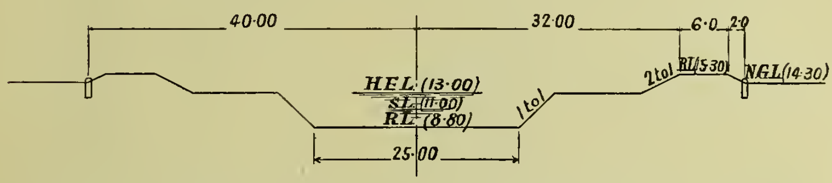


FIG. 144.—Baguria Canal, Section below Head.

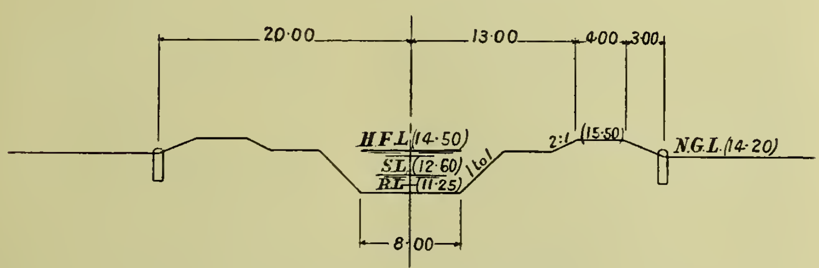


FIG. 145.—Sirsawia Canal (below Head).

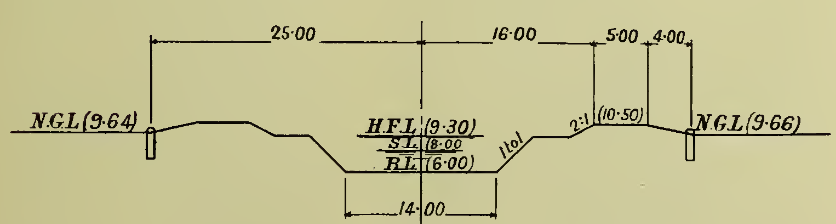


FIG. 146.—Gafaria Canal, Section below Head.

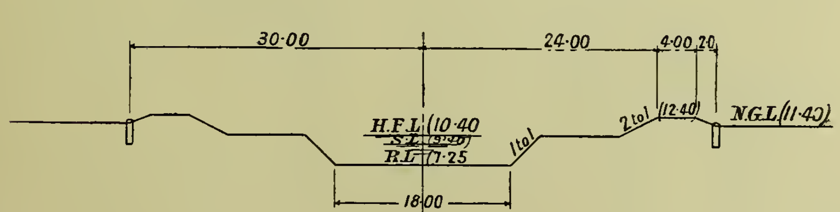


FIG. 147.—Kâsad Canal, Section below Head.

Fig. 148 and Plate LIII. are from the second edition of this work and show the longitudinal and cross sections of a number of typical Egyptian canals.

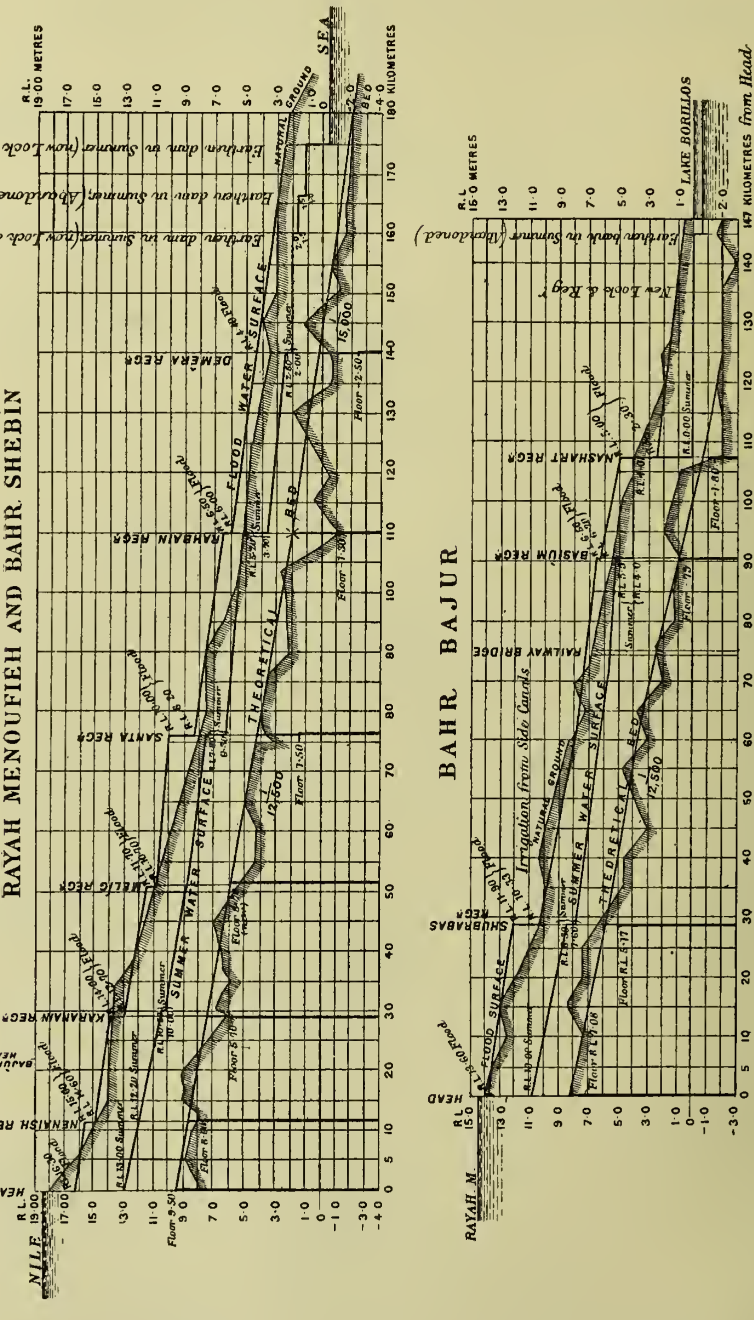


FIG. 148.—Typical Longitudinal Sections of Canals.

The following tables have been sent us by the Inspectors of the circles: Mr H. G. Finlaison of the First Circle, and Mr L. N. Cooper of the Third:—

TABLE 228.—MAIN CANALS IN THE FIRST CIRCLE (1912).

Name.	Length.	Bed.			Depth of Water.			Discharge, cubic metres per second.		
		Width at Head.	Width at Tail.	R.L.	Flood.	Winter.	Summer.	Flood.	Winter.	Summer.
	kilometres	metres	metres	metres	metres	metres	metres			
Rayah Tewfiki	65	35	30	10·60	4·60	Variable	Variable	200	120	80
Ismailia	225	16	8	12·00	3·70	3·00	2·80	60	36	36
Sharkawia	30	10	8	12·20	4·80	2·60	2·80	60	36	25
Shebini	46	10	...	10·00	2·50	2·50	2·00			
Khalili	30	8	3	10·50	3·30	3·00	2·30			
Bassussia	24	8	8	12·90	4·10	3·00	1·90	27	17	7
Filfila Mustagadda	35	5	3	10·90	2·80	2·50	2·25	8·5	8	7
Bahr Moes	88	20	12	8·00	4·50	4·00	2·50			
Bahr Fakus	33	20	...	5·50	2·80	2·00	1·80			

TABLE 229.—TYPICAL SECTIONS OF CANALS IN THE THIRD CIRCLE (1912).

Name of Canal.	Season.	Bed Width, Mean, in metres.	Area of Cross Section, in cubic metres.	Slope.	Mean Velocity, metres per second.	Discharge in Canal, cubic metres per second.
Rayah Behera	Flood	32·00	220·0	1/14,300	·91	200
	Summer	32·00	144·0	1/14,300	·74	106
Nubaria *	Flood	15·0	70·0	1/12,500	·70	49
	Summer	15·0	40·0	1/10,000	·32	12·8
Abu Diab †	Flood	10·0	29·0	1/20,000	·69	20·0
	Summer	10·0	12·0	1/20,000	·36	4·3
El Hager	Flood	8·00	23·0	1/11,400	·51	11·7
	Summer	8·00	9·6	1/10,000	·49	5·0
Khandak Gharbi ‡	Flood	16·0	47·0	1/14,000	·63	29·6
	Summer	16·0	25·5	1/18,000	·51	13·0
Khandak Sharki §	Flood	13·0	69·0	1/14,000	·81	55·6
	Summer	13·0	34·0	1/18,000	·70	23·8
Rosetta ‖	Flood	7·00	20·5	1/14,000	·42	8·6
	Summer	7·00	9·0	1/14,000	·39	3·5

* Flood canal below kilo 10.
† The tail reach is fed in summer by Khandak Gharbi Canal.
‡ and § A part of the discharge supplies the Mahmudia Canal.
‖ The lower reach is directly fed by the Nile in summer.

Plate LIV. gives type sections of drains which are maintained by dredging:—

121. **Dredging.**—The following note has been kindly written for us by Mr Phillpotts, Manager of the Egyptian Dredging Company:—

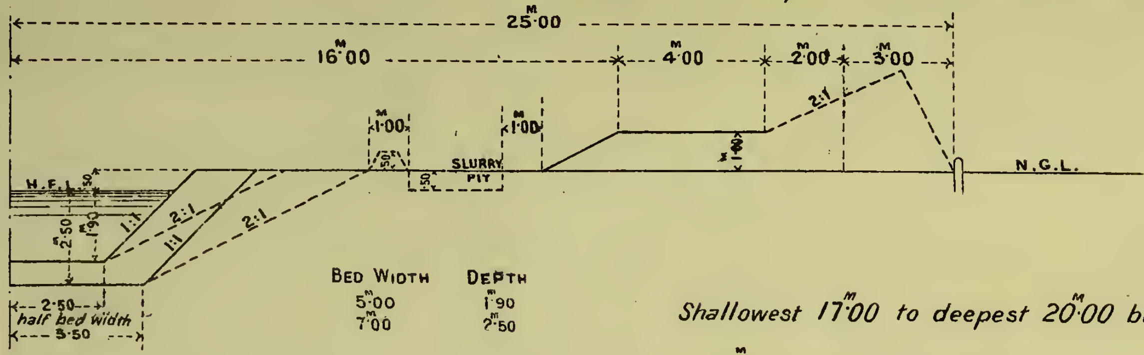
"*Bucket Dredgers* work well in hard sand, mud and anything except stiff sticky clay or hard virgin earth, provided the buckets are of good shape: and so much depends on this, that with a bad-shaped bucket working in sand, a number of buckets will remain full till after passing the shoot, and the contents will be returned again to the canal. The buckets should be made with plenty of taper in every direction. These dredgers are much heavier than either sand or grab dredgers, and must necessarily draw much more water, which prohibits their use in the smaller canals or drains; but when they can be used they are much more efficient for earth or mud, both as regards output and duty.

Centrifugal Sand or Mud Pump Dredgers work well in any sort of soft mud or sand. They require a considerable amount of attention on the part of the operator to ensure the delivery of a good thick mixture of sand and water, otherwise there would be a loss of fuel in simply pumping water instead of mud or sand. The efficiency is greatly increased by the application of an arrangement of steel cutters working round the outside of the suction nozzle, and the dredger slewed regularly from side to side of the canal with light chains driven by worm gearing.

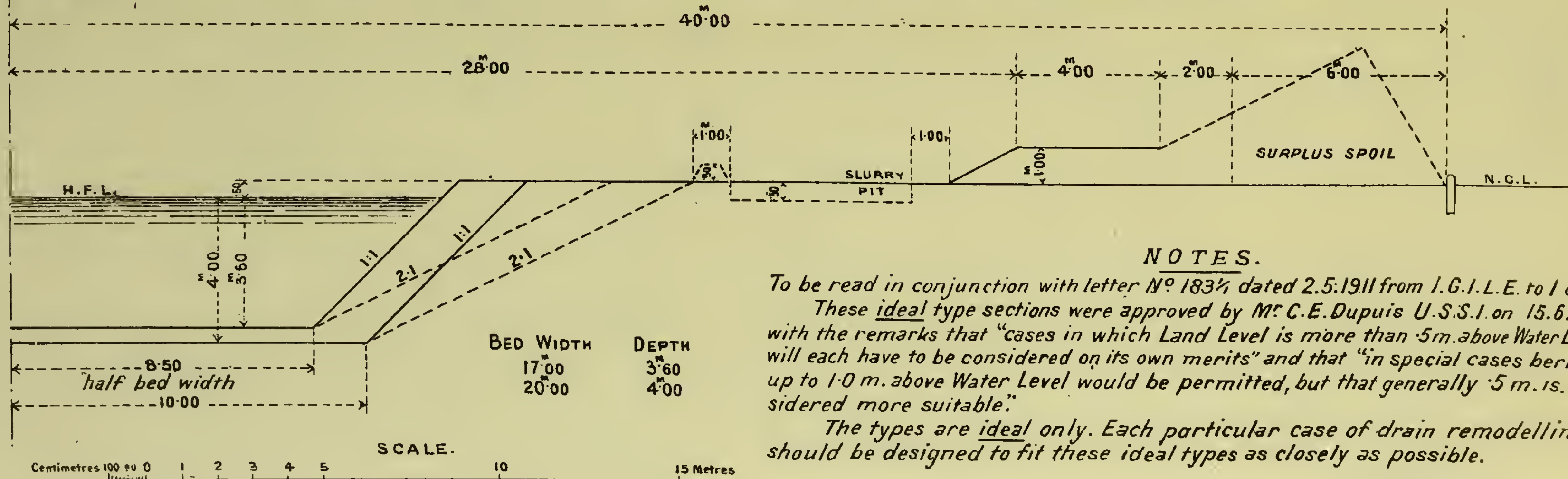
The water pumped is generally between eight to ten times that of mud or sand. The average lift is 3 to 4 metres.

IDEAL TYPE SECTIONS FOR DRAINS, THAT WILL BE MAINTAINED BY MEANS OF DREDGERS.

Shallowest 5·00 m to deepest 7·00 m bed widths inclusive.



Shallowest 17·00 m to deepest 20·00 m bed widths inclusive.



NOTES.

To be read in conjunction with letter Nº 183⅟ dated 2.5.1911 from I.G.I.L.E. to I of Ir.

These ideal type sections were approved by Mr. C.E. Dupuis U.S.S.I. on 15.6.1911 with the remarks that "cases in which Land Level is more than ·5 m. above Water Level will each have to be considered on its own merits" and that "in special cases berms up to 1·0 m. above Water Level would be permitted, but that generally ·5 m. is considered more suitable."

The types are ideal only. Each particular case of drain remodelling should be designed to fit these ideal types as closely as possible.

G. B. IRELAND,
Acting Inspector General of Irrigation

E. & F. N. Spon Ltd London

A 12-inch pump requires an engine which will indicate from 80 to 100 horse-power, including power for driving cutters.

In the first kilometre of a canal it pays to dredge the silt into hopper barges and drag them out into the Nile and there discharge the material. Elsewhere a long couloir deposits the material into slurry pits, dug annually on the berm. In some cases, where the berm is far off, the bucket dredgers lift the silt into barges, from which it is pumped over the banks by sand pumps. With the sand pump long slurry pits are dug on the berm, and the silt and water combined is pumped into them ; as the water moves along it leaves all the silt behind, and the water is eventually taken back into the canal through a pipe at the end of the trench. These trenches should be about 500 metres long each, and well retired from the edge, or the percolation and infiltration of the water make the berm slip into the canal. The water should always return to the canal in front of, and not behind, the dredging.

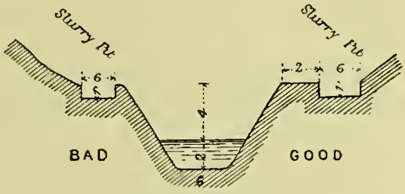


Fig. 149.

The Grab Dredgers deposit into the slurry pits on the berm. They can work in almost any kind of soil, whether hard or soft, by the use of suitable grabs. There are about four different types of grabs in common use with these dredgers. They are useful for deepening or widening canals in original soil under water, removing stones from sudds, and for weed clearing. They take up little room, can be mounted on pontoons designed for light draught of water, and consequently can follow a winding canal.

These dredgers are necessarily slow working, while the wear and tear is excessive owing to the varying strains brought on the machine by the sudden release of the load suspended from the end of the jib."

122. **Specifications.**—The more important points in a number of specifications written by Colonel Western and Mr Reid are given here for reference:—

Lock Gates.

Wrought Ironwork.—To be of dimensions figured on the drawings. All angles of girders to be of best girder angles, of single lengths, without joints. All plates of girders to be of the longest lengths obtainable, and no single plate to be less than 10 feet = 3·048 metres long. Where joints in webs are needed, such joints to be double covered with cover plates of $\frac{5}{16}$-inch iron, with two rows of rivets 3 inches = ·076 metre pitch on each side of joint. Rivet holes to be truly set out and cleanly punched. All rivets in welts of heel-post, along heel-post vertical girder, and along bottom girder of each gate, to be countersunk and flush-headed on outer face, so as to permit of the sheeting of the gate lying in close contact with the sill and quoin everywhere. All other rivets to be snap-headed, and no flawed, cracked or split rivets to be allowed to remain in the gate. All cranking of angles to be well and truly forged, and no cracked or reedy angles to be put into the works.

The sheeting of the gates and the webs of the girders to be of the best girder plates. The sluices on the gates to fit truly and well on to cast-iron fitting strips,

planed on face, and attached to the gate by countersunk bolts nutted up from the inside. All rivets of sluices to be flush on the face next the gate.

The heel and baling pins to be of Bessemer steel, turned and wrought to the dimensions shown on the drawings. The heel-pin to be shaped to the curve known as the "Equitangential tractrix." Length of generating tangent to be 4 inches, and pivot to be 7 inches long, curve commencing 1 inch from the apex. The bearing blocks of both pins to be cast to their true shape and chilled on their bearing surfaces, the pins being then wrought to fit them an easy sliding fit, and tempered to medium hardness. The sluice-lifting gear to be as shown on drawings, to be well made, and to work easily and smoothly, without backlash or play, other than the fair clearance of teeth. The blocks holding the lifting rods to be bored to fit the rod, and to be attached to the gate with their centres in a truly straight line.

The whole gate to be built in a good, workmanlike manner, of good material, well put together, with all joints butting closely and evenly.

Woodwork.—All woodwork to be of teak, sound, and well seasoned, no scarf to be less than 1 metre in length in the mitre post, and single lengths to be used for bottoms and tops of lock gates.

Cast Ironwork.—Quoins, Sills, Grooves, etc. All cast ironwork to be of best grey iron, soft, clean, and free from blow-holes, cracks, warps, or other blemish. The faces of the sills, where the gates bear against them, to be planed for a depth of 8 inches = ·203 metre from their upper faces; the ends of the sills where they meet the quoins to be also planed to make a true joint. The upper faces to be planed on a width of $\frac{1}{2}$ inch, so that a water-level may be moved along the sill to test its being truly horizontal when in position. The quoins where they bear against the sills to be planed, as also the chipping strips on which the gates bear when closed. The latter (chipping strips) to be scored down their entire length with one line each; such lines to be truly parallel to the axis of the quoin, and exactly at one quadrant's distance from one another. The blocks carrying the pivot and baling pin to be faced to the curvature of the quoins, the quoins themselves being also truly faced where the blocks bear. The ends of each piece of the quoins to be planed truly square to its length, so that the complete quoin shall be truly straight without the employment of packing of any kind.

All bolt-holes to be truly placed, so that no difficulty may arise in erecting.

Gearing.—The opening and closing gear for the lock gate to be as shown by the drawings. The winches to be well made and to work smoothly in all their parts.

The roller boxes for the opening chains to be as shown on the drawings, and to have each roller capable of being taken out and replaced without disturbing the box. All spindles of rollers to be of steel, hard tempered on their wearing surfaces. Bearings of rollers in boxes to be chilled. All bearings in winches to be bushed with phosphor bronze bushes $\frac{3}{8}$-inch thick, and all shafts to be of steel.

All necessary chains to be supplied and fitted, and to be of best-best, tested, close-link, crane chain.

The following "Instructions for Bidders," "Form of Tender," and "Specification" for the Zargun syphon from the pen of Colonel Western are good specimens of the best practice of the Ministry of Public Works:—

MAHMUDIA CANAL.—ZARGUN SYPHON.

Instructions for Bidders.

Adjudication on Wednesday the 18th January 1888.

Ministry of Public Works,
Director-General of Works.

1. All tenders must be made in duplicate on Government stamped paper, in accordance with the annexed form of tender, enclosed within two envelopes. The outer will be addressed to the Director-General of Works, and on the inner will be inscribed:

"Tender for the works of the Zargun Syphon—Mahmudia Canal."

2. To the tender will be attached a certificate of a deposit of £100 (one hundred pounds Egyptian) for the complete works in accordance with Art. 4 of the general clauses and conditions.

3. The prices will be written in letters and in figures.

4. The general conditions of the contract will be those in use at the Ministry of Public Works.

5. The contractor will be fined £2 (two Egyptian pounds) for each day of delay after the date agreed upon in the contract for the completion of the work.

6. Specimens of the materials to be employed must be submitted to the Director-General of Works within five days of the acceptance of the tender, and before the signature of the contract.

7. After the signature of the contract, the contractor will not be permitted to take a partner without the permission of the Ministry.

8. The Ministry of Public Works reserves to itself the right to reject any or all the tenders, without having to give any reasons for its decision.

9. Payments will be made monthly, and as soon as possible after the first day of the month.

10. Bidders are invited to attend at the opening of the tenders.

Form of Tender.

Adjudication of the 18th January 1888.

The undersigned........., a .... subject, resident at ...., engages himself to the Minister of Public Works to supply all the materials and execute all the works for the syphon and the diversion near Zargun, in accordance with the designs, specifications, and other pieces of the project, of which he acknowledges having taken full and complete cognisance, at the prices entered below :—

—	Syphon and Diversion, Rate in piastres tariff.	
	In Letters.	In Figures.
Excavation and filling (lump sum) . .		
,, of diversion per metre cube .		
Concrete per metre cube . . .		
&c.		

The undersigned binds himself to commence the works on the outside within ....days of the signature of the contract, and complete them within......... months of the same date.

Cairo, the ....

....

SPECIFICATION.

Description of Works.—The works to be executed consist of a syphon provided with two wrought-iron pipes of 1·56 metre diameter, with stiffeners, and the earthwork of the diversion, and the up- and downstream approaches.

General.—The work to be constructed and completed in accordance with the rules of art, in conformity with the drawings, and in accordance with the instructions of the Director-General of Works.

The axes of the work will be traced on the ground by the engineer delegated by the Ministry to superintend the work, and a bench-mark will be fixed by him to serve as a basis for determining levels of foundations, floors, &c. The contractor to furnish the workmen, materials, and instruments necessary for the engineer in charge to check the levels, widths, &c., of the work, whenever he may judge necessary. The contractor to make all arrangements at his own cost for the land needed for the execution of the work, and he will be responsible for all or any accidents which may happen during the execution of the work. The sheet piling or other protective works which may be necessary will be equally at the charge of the contractor.

None of the foundation works in concrete, masonry or pitching, to be commenced without the permission in writing of the engineer in charge; and in order to obtain this permission the contractor must give eight days' notice before the probable date on which he will commence his work.

Earthwork.—All the earthwork necessary for the execution of the masonry works will be paid for by a lump sum, and to include excavation and filling, as well as the transport and the levelling of excess earth, up to a maximum distance of 100 metres from the centre line of the work, in conformity with drawings and written instructions of the engineer in charge. Will be considered as earthwork necessary for the masonry work, and included within the lump sum, all the earthwork between the outer edges of the pitching of the up- and downstream approaches. The amount of earthwork at a lump-sum contract is approximative, and must be verified and accepted by the contractor at his risk and peril.

The earthwork of the diversion and its banks will be paid for by the metre cube, and in order to facilitate the measurement, sections of the natural ground will be left at the points indicated by the engineer in charge. The bottom of the excavation for foundations to be dressed off horizontally, in accordance with the plans; all excavation in excess to be refilled with brick masonry or concrete at the contractor's cost.

The filling in behind the masonry work will be carefully made in successive layers of ·50 metre, watered and rammed. They will be raised in the same measure as the masonry, and must never be more than 2 metres below the level of the masonry. All the earth in excess will be placed according to the plans and the written orders of the engineer in charge, and carefully dressed.

Ordinary Concrete.—The ordinary concrete used in the foundations of the masonry work and for the syphon will be composed of 1 part mortar and 2 parts ballast, measured dry. The ballast will consist of hard stone or well-burnt brick; 80 per cent. must be able to pass through a ring ·025 metre diameter, and the rest, or 20 per cent., through a ring ·015 metre diameter. The ballast must be well washed, and must be soaked in clean water for at least twelve hours immediately

before it is used. The mortar will be composed of 1 part of freshly burnt and slaked lime and of 1½ parts of pounded bricks passed through a sieve of ·001 metre. The ballast will be evenly spread over a clean area; to the ballast will be added in the prescribed proportion the mortar, previously mixed dry. The whole will be turned at least twice over by a shovel whilst the necessary water is added. After this mixture the concrete will be immediately used, and for no reason will a delay of more than two hours be permitted between the times of mixing and employing.

Each layer of concrete must not exceed ·15 of a metre, and it must be rammed with iron rammers until it attains a thickness of ·11 of a metre. All surfaces must be clean and constantly watered. Before spreading a fresh layer the preceding one must be scrabbled.

Brick Masonry.—The bricks to be of good quality, with regular faces, and well burnt; when immersed in water for twelve hours the weight of water absorbed must not exceed one-eighth of the weight of the brick when dry. The bricks to be immersed in clean water for at least twelve hours immediately before being used. A sample of these bricks must be deposited at the office of the Director-General of Works. They will be set in mortar composed of 1 part of freshly burnt and slaked lime and 1½ parts of pounded brick, or "homra." All "homra" employed on the works will be composed solely of clay balls or bricks well burnt, so that after twelve hours of immersion in water they do not absorb more water than one-eighth of their own weight when dry. The mortar will be mixed in a mortar-mixing machine with the necessary quantity of water. On no account will any but recently made mortar be used. Neither brickbats nor cracked bricks must be used for filling without the written permission of the engineer in charge. All the courses must be perfectly level. Bricks of ·11 metre × ·05 metre × ·22 metre will be used by preference, and in such a manner that 1 metre in height will contain 18 courses. The dimensions of the bricks, however, may be changed with the written permission of the Director-General of Works.

English bond will be used whenever possible. Each brick will be placed on a bed of mortar and pressed home so that all the joints are filled, and on no account will the mortar be introduced afterwards. No part of the masonry must be more than 2 metres higher than the neighbouring parts, and the connecting slopes must be 2 to 1.

Brick Floor.—The part of the floor in brickwork will be set in mortar composed of 1 part of Portland Cement (English) and 2 parts of coarse sand, angular and washed, unable to pass through a sieve of ·001-metre meshes. The sand to be clean and to contain no foreign matters. The Portland Cement to be of a good mark, and to resist a tension of 30 kilograms per (·01 metre × ·01 metre) square centimetre after seven days' immersion.*

Ashlar.—The ashlar in the top courses of the walls to be of the best quality of Tura or Abbassia stone, of an exact height, with well-dressed faces. Their cubic contents not to be less than ·90 metre × ·60 metre × ·40 metre. The thickness of the joints not to be over ·015 metre or less than ·007 metre. The mortar to be composed of 1 part of cement and 2 parts of sand.

Pointing.—All exposed faces of walls to be pointed with Portland cement mortar composed of 1 part cement and 2 parts of coarse sand, angular and washed; before pointing, the joints to be raked out to a depth of ·02 metre and well washed.

* This answers for small quantities of cement.

The pointing to keep pace with the masonry, and to be done while the mortar in the joints is still fresh and has not set. The cost of the pointing to be included in the cost of the brick masonry and the ashlar work.

Pitching.—The rubble pitching to be obtained from the Tura or Abbassia quarries, and the blocks to weigh 50 kilograms each as a mean, no block to weigh less than 30 kilograms. The face stones will be carefully placed by hand, and the interstices filled with splinters or small pieces of stone.

General.—The faces of the masonry to be carefully built, and kept clean, and the unfinished parts to be constantly watered. The iron pipes not to be put in position except in the presence of the engineer in charge. The contractor to inform the engineer in charge beforehand of the date on which he will be ready to put each pipe in place. No complaint will be entertained of a delay to the work owing to the inability of the engineer to assist immediately.

No extra payment will be made for the putting in position and fixing of the iron pipes. The lime to be made of Tura stone, and to be burnt and slaked on the works.

Wrought-iron Pipes.—All ironwork to be of the best quality, and of the dimensions figured on the drawings. All plates, angles, and cover plates to be of single lengths. All joints in the plates to be alternately on the right and left of the pipes, exactly opposite each other on the same plane. The joints in the cover plates to fulfil the same conditions on a plane perpendicular to the last. All joints to be single covered on their outer surface, with cover plates of the same thickness as the plates, on a width of 6 inches. The diameter of rivets to be $\frac{3}{4}$ inch, and pitch 3 inches. The $\perp$-iron stiffeners to be 4 inches $\times$ 2 inches $\times \frac{1}{2}$ inch, with rivets $\frac{1}{2}$ inch diameter and 3 inches pitch. Rivet holes to be truly set out and cleanly punched. The rivets are to be snap headed, and no flawed, cracked, or split rivets to be allowed to remain in the pipes. The contact between the plates and cover plates, or plates and stiffeners, to be perfect. All the angle irons to be well and carefully forged, and no cracked or reedy angles to be put into the work. The whole pipe to be built in a good, workmanlike manner, of good material, well put together, with all joints butting closely and evenly. The inner and outer surface of the pipes to be painted with two coats of tar before leaving the shops, but not before they have been inspected by the engineer in charge, or some other person delegated by him for this purpose.

123. **Maintenance.**—The following note by Mr C. E. Dupuis, adviser to the Ministry of Public Works, will be found full of useful information. We differ from Mr Dupuis on the question of flush irrigation in summer, but we are heartily in accord with him on the subject of the canals being designed solely for flood conditions. It is the basis of all successful irrigation. (For references to *Maintenance* see page 609.)

"In considering the necessity for canal clearances far too much thought is generally given to summer supply; and it cannot be too often repeated or insisted on that canals should almost always be designed to suit their flood supplies, and to carry those supplies efficiently with the minimum of silt deposit, with little or no thought for their summer supplies.

A canal that can carry its flood supply will certainly always be able to carry

its summer supply without difficulty, and the exact level at which it will run when so doing is not a matter of much consequence as regards the design of the channel itself (though it may be a ruling consideration for the design of the outlets taking off it), so long as means of controlling the supply to the canal at its head exist, so that it may always be given its proper share of water no matter what level may be required to give the corresponding discharge.

When small branch canals take off large main lines near their heads where the water level in summer is very low relatively to the land and where regulation is undesirable, the branches, if designed to suit their flood supplies, would run dry in summer, and the usual practice is to dig them so deep that, even with the lowest summer levels in the main line, they draw their fair share of water; this of course is necessary, but the people dependent on such canals expect free flow water in flood from them just as much as elsewhere; and with the large rise of levels necessary to effect this, the sections of the canals become excessive, and to avoid their carrying disproportionately large discharges, and inundating the lands at their tails, they are heavily regulated on at short intervals, with the object of diminishing their surface slopes, and consequently their discharges, while retaining the desired high levels. Consequently they become a series of basins with a sluggish current, in fact a chain of silt traps.

In such cases, as noted above, the deep clearance is necessary, and the best remedy is to maintain such canals as summer canals only, closing them entirely in the flood, and effecting the flow irrigation of the flood season by an independent system of small high-level Nili Canals.

A very instructive example of this is given by Mr Willcocks on p. 337 of the second edition of *Egyptian Irrigation*, and the works there described have proved of the greatest value, and are being further extended and developed on the same lines (see page 558).

Of late years a good deal of attention has been bestowed on the question of flood rotations, in conjunction with recent developments on the subject of 'alternate running' in India. I think that it may be safely assumed that any small irrigation canal will be most efficient, and least likely to do injury to adjacent lands by infiltration, if it be run at a high level for a short period so as to irrigate thoroughly the tract commanded by free flow, and then lowered or closed till another watering is necessary. Remembering that we have to consider flood conditions to determine the section of a canal, a rotation system based on periods of one week each, at once suggests itself, and the most suitable general rule to follow would appear to be to design such small canals to irrigate the whole area dependent on them in one week; as during the flood season practically the whole area commanded will be under cultivation, and with the canal running in alternate weeks, each individual field would receive a watering once in fourteen days, which is just about suitable for the crops in the ground at that season.

Such a canal would be best adapted to summer conditions by being run full for about three days, during which time it could irrigate about 40 per cent. of the area commanded, and then closed for whatever interval the conditions of supply might necessitate—the same outlets would answer for this as for the flood irrigation, and such lift machines as might be necessary being placed outside the culverts, their size could be treated as a private matter to be arranged by the proprietors of

the lands concerned amongst themselves; at any rate their existence need not affect the design of the outlets themselves.

Where it was impossible to provide flood levels in summer,* the canal would have to draw a less supply for a longer time, and the size of the outlets being no longer proportioned to the discharge, some system of internal rotations would be required.

Returning to flood conditions, if we assume a depth of 8 centimetres of water to be required for each watering, the canal should discharge about 350 cubic metres per week or 50 cubic metres per day for every acre commanded.

This allowance is small rather than large, but under any system of intermittent running deficiencies can always be made up (if water is available) by running extra days in times of pressure, as, for instance, at the beginning of the flood season, when the allowance of 8 centimetres depth would never be sufficient for the 'sharaki' floodings.

The required full supply discharge at any point of such a canal can therefore always be at once determined from a consideration of the area served by the canal below that point.

The section required to give that discharge depends of course on the velocity of flow, which again depends on the surface slope of the water in the canal. The surface slope of the canal is determined by the slope of the land, the object being to command the land just sufficiently to give flow irrigation to all but exceptionally high patches of land when running full supply.

In designing the section of such a canal therefore the first thing necessary is a longitudinal section showing the levels of the land to be irrigated along its line.

A line approximately parallel to the land level line, and averaging about 25 centimetres above it, will then give a suitable full supply level line for the water of the canal, and should generally for convenience be chosen so as to give a uniform slope of so many centimetres per kilometre.

Considering then the areas of land served at a series of points along the line of the canal, we know the discharges required at each of those points, and we know the slope of the water surface; a few calculations of the velocities given by that slope in canals of different sections will determine approximately suitable cross sections for the canal at each of those points.

Measuring down the depths of those sections from the water surface line at each of the points concerned on the longitudinal section will fix the correct bed level of the canal at those points, and for simplicity of record and convenience in future maintenance it will generally be best to assume a straight line of a uniform slope of so many centimetres per kilometre (which corresponds approximately with the line joining the points indicating the correct bed levels) as the true bed level line.

This bed level line will generally have a slightly less inclination than the water surface line corresponding to the gradually diminishing depth of the canal towards its tail, and it may be horizontal or even slope upwards—this extreme case occurring in a canal with a very low surface slope and heavy irrigation, and consequently rapidly diminishing section and depth.

* We consider flush irrigation in summer good where the land slopes well to the drains, as it does in the north; but in the flat basin lands, especially where the soil is sandy, we consider flush irrigation in summer a curse and no blessing.—AUTHORS.

The water surface slope and bed slope of the canal, and its bed width at a series of points having been thus fixed, any remaining details can be readily interpolated, and the water section of the canal is fully determined.

The only point of any difficulty in the above calculation is the determination of the canal's bed width and depth from its required discharge and known surface slope, but if a certain standard table of proportionate bed widths and depths be adopted, the range of possible selections in any case is restricted within very narrow limits, and a few rough calculations on a trial and error system will fix the most suitable section with considerable accuracy in a few moments—such a table of proportionate bed widths and depths is given in Table 230, but it must be remembered that these proportions are purely arbitrary, and capable of considerable and advantageous modification to suit special cases.

Table 231 gives the approximate velocities of flow in canals of typical section with different surface slopes.

Table 232 gives in tabular form the results of calculations of the above kind in a large number of common cases.

We can now proceed to the consideration of the case of larger branch canals feeding one or more distributing canals of the kind hitherto considered.

Such canals may conveniently be called 'branch' canals, the smaller class of canals being called 'distributing' canals.

The essential function of a 'branch' canal is to feed its 'distributaries,' at whatever levels the available supplies or exigencies of the moment may necessitate, and it is properly regarded as a carrying and not a distributing canal, and should be freed as far as possible from the disturbing influence of direct irrigation. It should be liberally provided with regulators, suitably placed below the heads of its various distributaries, so that each of those distributaries may be given any required level at any time.

Its full supply level should be determined primarily by the levels required at the heads of its various distributaries, without reference to ground levels; but as those distributaries only run at high levels in alternate weeks, and as a branch canal feeding several distributaries will give full supply to half of them one week and to the other half of them in the other week, and will therefore in its upper reaches run with an approximately constant discharge, it is desirable to design a branch canal so that when running its ordinary full supply with all its regulators open, its water surface shall be at or slightly below ground level.

The full supply level can be given at any time to any one of the distributaries by ponding up the water a little in the branch, by partially closing the regulator below that distributary head; the necessity even for this can be avoided if the distributing canals be made to overlap each other slightly, so that the tail of one system irrigates the lands about the head of the next; and in this case it is possible to have a branch canal that in no part of its course at any time commands the adjacent lands, irrigating the whole area by free flow by means of carefully arranged distributaries, which again run at a high level only in alternate weeks. All possible danger of damage from infiltration can be thus avoided.

Without, however, going in for quite such refinements, it will generally be suitable to design a branch canal so as to carry its normal full supply at a level about 25 centimetres below the levels required to give full supply level at the heads of its various distributaries; those levels being about 25 centimetres above

land level, the normal full supply level of the branch will be generally at about land level.

As a branch canal gives its various distributaries high levels in different weeks, and as those distributaries will take a discharge of 50 cubic metres per acre commanded per day in their high weeks; and one-fourth of that amount, or 12 cubic metres per acre, in their low weeks, the branch should carry a discharge of $\frac{50+12}{2}$ $=31$ or 30 cubic metres per day for every acre that it commands, thus allowing a small margin for waste, the maintenance of navigation, and water escaped at the tail.

Strictly speaking, the distributing canals carrying 50 cubic metres per acre per day in their high weeks should be dry in their low weeks; and were this possible, it would be convenient, and probably highly beneficial to the lands concerned; but practically it will not generally be found possible to effect it, though little or no account can be taken of the small discharges that may be run in the low weeks for irrigating purposes.

Branch canals should therefore, in conformity with this theory, be designed to carry discharges of about 30 cubic metres per acre commanded per day with surface levels at about land level; the extra carrying power given by this comparatively low surface level should be very valuable in enabling such canals to run extra discharges in times of pressure, as at the commencement of the flood, when all distributing canals would for a short time like, if possible, to run full supply continuously for sharaki irrigation.

Larger canals still, such as those that feed several 'branches,' may conveniently be called 'main' canals; and as it has already been shown that branch canals should run approximately constant discharges at their head with an ordinary 'full supply' amount of 30 cubic metres per acre commanded per day, so the main lines also which feed them should run approximately constant discharges with ordinary full supply amounts of 30 cubic metres per acre per day for the whole area that they command, with surface levels similarly at about land level.

Exactly the same line of argument can be followed in designing drain sections as has been indicated above for canals.

The figure for the calculation of the discharge for which it is required to provide has of late years generally been taken at 12 cubic metres per acre drained per day; but, as in the case of canals so in drains, a bigger figure should be adopted for small drains than for large ones, as though no attempt to establish rotations on drains is desirable, the smaller drains will necessarily be much influenced by the intermittent flow of the small canals in their vicinity.

Probably an allowance varying from 8 cubic metres for very large drains to 20 cubic metres for very small ones would be found suitable.

In designing the drain the procedure should be exactly similar to that for canals; the first thing required is the longitudinal section showing the land levels; on this a line for the highest desirable maximum level of the drain should be laid down, approximately parallel to the land surface and (if possible) not less than 50 centimetres below it; the level of this line is of course determined at its lower end by the maximum level of the lake or main drain into which the channel under consideration discharges; the slope of the line (which for the lower reaches of a large drain will generally be a very low one) will determine the velocity of flow, and consequently

the section required to pass the discharge at any point, and the depths of those sections will fix the bed line.

It may be noted that as in a canal which has a constantly diminishing discharge and section the slope of the bed line is generally considerably less than the slope of the water surface, so in a drain which has a constantly increasing discharge and section the slope of the bed line will generally be considerably greater than the slope of the water surface.

Drainage water should also only be admitted into public drains through properly constructed and sanctioned inlets, preferably consisting of iron pipes, of sizes proportioned to the areas drained, and where free flow drainage of the lands concerned is not possible at all seasons, the proprietors could be allowed to erect and work pumps situated a little outside the limits of Government land and a little off the lines of the private drains leading to the inlets, so that, a small sluice having been constructed in such a private drain opposite the pumps, the water could either be allowed to flow directly to the inlet by gravitation through the open sluice, or, the sluice having been closed, the water could be lifted round it by the pump to the level necessary to enable it to discharge into the public drain.

Table 230.—Approximately Suitable Proportions between Bed Width and Depth in Canals of Various Sizes.

Bed Width. Metres.	Suitable Depth. Metres.	Sectional Area with 1 to 1 Side Slopes. Square metres.	Bed Width. Metres.	Suitable Depth. Metres.	Sectional Area with 1 to 1 Side Slopes. Square metres.
1	1·0	2·0	15	3·5	64·7
2	1·5	5·2	16	3·6	70·6
3	2·0	10·0	17	3·7	76·6
4	2·0	12·0	18	3·8	82·8
5	2·0	14·0	19	3·9	89·3
6	2·2	18·0	20	4·0	96·0
7	2·4	23·6	25	4·5	132·7
8	2·6	27·6	30	5·0	175·0
9	2·8	33·0	35	5·5	222·7
10	3·0	39·0	40	6·0	276·0
11	3·1	43·7	45	6·5	334·7
12	3·2	48·6	50	7·0	399·0
13	3·3	53·8			
14	3·4	59·2			

TABLE 231.—APPROXIMATE MEAN VELOCITY OF FLOW IN CANALS OF DIFFERENT SLOPES AND SECTIONS IN FAIR AVERAGE CONDITION.

Canal Section.		Velocities in metres per second for the following Surface Slopes.												
Bed Width.	Depth.	1 centimetre per kilometre.	2 centimetres per kilometre.	3 centimetres per kilometre.	4 centimetres per kilometre.	5 centimetres per kilometre.	6 centimetres per kilometre.	7 centimetres per kilometre.	8 centimetres per kilometre.	9 centimetres per kilometre.	10 centimetres per kilometre.	12 centimetres per kilometre.	15 centimetres per kilometre.	20 centimetres per kilometre.
metres	metres													
1	1·0	·08	·11	·14	·16	·18	·19	·21	·22	·24	·25	·27	·30	·35
2	1·0	·09	·13	·16	·18	·20	·22	·24	·25	·27	·28	.30	·33	·39
2	1·2	·09	·14	·17	·20	·22	·24	·26	·28	·30	·31	·33	.37	·43
2	1·5	·10	·15	·18	·21	·24	·27	·29	·31	·33	·34	·37	·41	·48
3	1·5	·11	·17	·21	·25	·26	·29	·31	·33	·35	·37	·40	·45	·54
3	2·0	·13	·19	·24	·28	·31	·34	·37	·39	·42	·44	·48	·54	·62
4	2·0	·14	·20	·25	·30	·33	·36	·39	·42	·45	·47	·51	·57	·65
5	2·0	·15	·21	·26	·31	·34	·37	·40	·43	·46	·48	·54	·60	·69
6	2·2	·17	·23	·28	·33	·37	·40	·43	·46	·49	·52	·57	·64	·73
7	2·4	·18	·25	·30	·35	·40	·43	·46	·49	·53	·56	·62	·68	·78
8	2·6	·19	·26	·32	·37	·42	·46	·49	·52	·56	·59	·65	·72	·82
9	2·8	·20	·28	·34	·39	·44	·48	·52	·55	·59	·62	·68	·75	·87
10	3·0	·21	·29	·35	·41	·46	·50	·54	·58	·62	·65	·71	·79	·91
11	3·1	·21	·30	·37	·43	·47	·52	·56	·60	·64	·67	·73	·82	·94
12	3·2	·21	·31	·38	·44	·49	·54	·58	·62	·66	·69	·75	·84	·97
13	3·3	·22	·32	·39	·45	·50	·55	·59	·63	·67	·71	·77	·86	1·00
14	3·4	·22	·33	·40	·46	·52	·57	·61	·65	·67	·73	·79	·88	1·02
15	3·5	·23	·33	·41	·47	·53	·58	·62	·66	·70	·74	·80	·90	1·04
16	3·6	·23	·34	·42	·48	·55	·60	·64	·68	·72	·76	·83	·93	1·07
17	3·7	·24	·35	·43	·50	·56	·61	·66	·70	·74	·78	·85	·96	1·10
18	3·8	·25	·36	·45	·51	·58	·63	·68	·72	·76	·80	·87	·98	1·13
19	3·9	·26	·37	·46	·53	·59	·64	·69	·74	·78	·82	·90	1·01	1·16
20	4·0	·27	·38	·47	·54	·60	·66	·72	·77	·81	·85	·92	1·04	1·19
25	4·5	·29	·41	·50	·58	.65	·71	·77	·83	·88	·92	1·00	1·12	1·30
30	5·0	·32	·44	·54	·63	·70	·77	·83	·89	·94	·99	1·09	1·22	1·41
35	5·5	·34	·47	·58	·67	·75	·82	·89	·96	1·02	1·07	1·17	1·31	1·52
40	6·0	·37	·51	·62	·72	·81	·89	·97	1·04	1·10	1·15	1·25	1·40	1·62
45	6·5	·39	·55	·66	·77	·87	·95	1·03	1·11	1·17	1·22	1·33	1·50	1·73
50	7·0	·41	·58	·70	·82	·92	1·01	1·09	1·17	1·24	1·30	1·41	1·60	1·83

TABLE 232.—TABULAR STATEMENT OF THEORETICALLY SUITABLE SECTIONS FOR DISTRIBUTING CANALS IRRIGATING DIFFERENT AREAS, ON THE BASIS OF 50 CUBIC METRES DISCHARGE PER ACRE COMMANDED PER DAY. DIMENSIONS IN METRES.

Area served in acres.	Canal Section.	Slope of Canal Water Surface in centimetres per kilometre.												
		1	2	3	4	5	6	7	8	9	10	12	15	20
1,000	Bed width	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	1·0	1·0	1·0	1·0
	Depth .	1·6	1·4	1·2	1·1	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
2,000	Bed width	3·0	3·0	3·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0
	Depth .	1·9	1·5	1·4	1·6	1·5	1·4	1·3	1·3	1·2	1·2	1·1	1·1	1·0
3,000	Bed width	4·0	3·0	3·0	3·0	3·0	3·0	3·0	2·0	2·0	2·0	2·0	2·0	2·0
	Depth .	2·0	1·9	1·7	1·6	1·6	1·5	1·4	1·6	1·5	1·5	1·4	1·3	1·2
4,000	Bed width	5·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	2·0	2·0
	Depth .	2·0	2·0	2·0	1·9	1·8	1·8	1·7	1·7	1·6	1·5	1·5	1·6	1·5
5,000	Bed width	6·0	5·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	2·0
	Depth .	2·1	2·0	2·0	2·1	2·0	1·9	1·8	1·8	1·7	1·7	1·6	1·5	1·6
6,000	Bed width	6·0	6·0	5·0	4·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0
	Depth .	2·3	2·1	2·0	2·1	1·9	2·1	2·0	1·9	1·8	1·8	1·7	1·6	1·5
7,000	Bed width	7·0	6·0	6·0	5·0	4·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0
	Depth .	2·3	2·2	2·0	2·0	2·1	2·0	2·1	2·0	1·9	1·9	1·8	1·7	1·6
8,000	Bed width	7·0	6·0	6·0	5·0	5·0	5·0	4·0	4·0	3·0	3·0	3·0	3·0	3·0
	Depth .	2·5	2·3	2·1	2·1	2·0	1·9	2·1	2·0	2·1	2·0	1·9	1·8	1·7
9,000	Bed width	8·0	7·0	6·0	6·0	5·0	5·0	5·0	4·0	4·0	4·0	3·0	3·0	3·0
	Depth .	2·6	2·3	2·2	2·1	2·1	2·0	1·9	2·0	2·0	1·9	2·0	1·9	1·8
10,000	Bed width	8·0	7·0	7·0	6·0	6·0	6·0	5·0	5·0	4·0	4·0	4·0	4·0	3·0
	Depth .	2·7	2·4	2·2	2·2	2·1	2·0	2·0	2·0	2·1	2·0	2·0	1·9	2·0
12,000	Bed width	9·0	8·0	7·0	7·0	6·0	6·0	6·0	5·0	5·0	5·0	5·0	4·0	4·0
	Depth .	2·8	2·5	2·4	2·3	2·3	2·1	2·0	2·1	2·0	2·0	1·9	2·0	2·0
15,000	Bed width	10·0	9·0	8·0	7·0	7·0	7·0	7·0	6·0	6·0	6·0	6·0	5·0	5·0
	Depth .	3·0	2·7	2·5	2·4	2·3	2·3	2·2	2·3	2·2	2·1	2·0	2·0	1·9
20,000	Bed width	13·0	10·0	9·0	9·0	8·0	8·0	7·0	7·0	7·0	7·0	6·0	6·0	6·0
	Depth .	3·3	3·0	2·8	2·6	2·6	2·5	2·5	2·4	2·3	2·2	2·3	2·2	2·1
25,000	Bed width	15·0	12·0	11·0	10·0	9·0	9·0	8·0	8·0	8·0	8·0	7·0	7·0	7·0
	Depth .	3·5	3·2	3·1	2·9	2·8	2·7	2·7	2·6	2·5	2·4	2·4	2·3	2·2

Note.—All calculations made for side slopes of 1 to 1 for the water section.

TABLE 233.—TABULAR STATEMENT OF THEORETICALLY SUITABLE SECTIONS FOR BRANCH AND MAIN CANALS IRRIGATING DIFFERENT AREAS, ON THE BASIS OF 30 CUBIC METRES DISCHARGE PER ACRE SERVED PER DAY. DIMENSIONS IN METRES.

Area served in acres.	Canal Section.	Slope of Canal Water Surface in centimetres per kilometre.												
		1	2	3	4	5	6	7	8	9	10	12	15	20
10,000	Bed width	6·0	6·0	5·0	4·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0
	Depth .	2·3	2·1	2·0	2·1	1·9	2·1	2·0	1·9	1·8	1·8	1·7	1·6	1·5
20,000	Bed width	9·0	8·0	7·0	7·0	6·0	6·0	6·0	5·0	5·0	5·0	5·0	4·0	4·0
	Depth .	2·8	2·5	2·4	2·3	2·3	2·1	2·0	2·1	2·0	2·0	1·9	2·0	2·0
30,000	Bed width	12·0	10·0	9·0	8·0	8·0	8·0	7·0	6·0	6·0	6·0	6·0	5·0	5·0
	Depth .	3·2	2·8	2·7	2·6	2·5	2·4	2·3	2·4	2·3	2·2	2·1	2·0	2·0
40,000	Bed width	14·0	12·0	10·0	9·0	9·0	9·0	8·0	7·0	7·0	7·0	7·0	6·0	6·0
	Depth .	3·5	3·1	2·9	2·9	2·8	2·7	2·6	2·6	2·5	2·4	2·3	2·2	2·1
50,000	Bed width	16·0	13·0	11·0	10·0	10·0	10·0	9·0	8·0	8·0	8·0	8·0	7·0	7·0
	Depth .	3·7	3·3	3·1	3·1	3·0	2·9	2·9	2·8	2·7	2·6	2·5	2·5	2·3
75,000	Bed width	20·0	16·0	15·0	13·0	13·0	13·0	12·0	12·0	11·0	10·0	10·0	9·0	8·0
	Depth .	3·8	3·6	3·5	3·4	3·3	3·2	3·2	3·1	3·0	3·0	2·8	2·8	2·5
100,000	Bed width	25·0	20·0	18·0	16·0	15·0	15·0	15·0	14·0	13·0	12·00	12·00	11·0	10·0
	Depth .	4·0	3·9	3·8	3·7	3·6	3·4	3·5	3·4	3·3	3·3	3·1	3·1	3·0
150,000	Bed width	30·0	25·0	25·0	20·0	20·0	20·0	18·0	17·0	16·0	16·0	15·0	14·0	13·0
	Depth .	4·5	4·3	4·0	4·0	3·9	3·8	3·8	3·7	3·6	3·6	3·5	3·4	3·3
200,000	Bed width	35·0	30·0	25·0	25·0	20·0	20·0	20·0	20·0	19·0	18·0	17·0	17·0	15·0
	Depth .	5·2	4·8	4·4	4·1	4·5	4·2	4·0	3·9	3·9	3·8	3·8	3·6	3·5
300,000	Bed width	40·0	35·0	30·0	30·0	30·0	25·0	25·0	25·0	25·0	25·0	20·0	20·0	20·0
	Depth .	6·0	5·4	5·3	4·7	4·5	4·7	4·4	4·2	4·0	3·8	4·2	4·0	3·8
400,000	Bed width	45·0	40·0	40·0	35·0	35·0	30·0	30·0	30·0	30·0	25·0	25·0	25·0	25·0
	Depth .	6·5	6·0	5·5	5·3	5·0	5·2	4·8	4·5	4·2	4·9	4·7	4·3	4·0
500,000	Bed width	50·0	45·0	45·0	40·0	40·0	35·0	35·0	35·0	35·0	30·0	30·0	25·0	25·0
	Depth .	7·0	6·5	6·0	5·8	5·5	5·6	5·2	4·8	4·4	5·4	5·0	4·5	4·4
750,000	Bed width	50·0	50·0	50·0	45·0	45·0	40·0	40·0	40·0	40·0	35·0	35·0	30·0	30·0
	Depth .	7·3	7·0	6·8	6·4	6·2	6·0	5·7	5·4	5·0	5·8	5·5	5·2	4·8
1,000,000	Bed width	55·0	55·0	50·0	50·0	50·0	45·0	45·0	45·0	45·0	40·0	40·0	35·0	30·0
	Depth .	7·5	7·0	7·3	7·1	6·9	6·5	6·2	5·9	5·7	6·3	6·0	5·8	5·0

Note.—All calculations made for side slopes of 1 to 1 for the water section.

TABLE 234.—TABULAR STATEMENT OF THEORETICALLY SUITABLE SECTIONS FOR DRAINS SERVING DIFFERENT AREAS, ON THE BASIS OF A DISCHARGE VARYING FROM 20 CUBIC METRES PER ACRE SERVED PER DAY FOR VERY SMALL DRAINS TO 8 CUBIC METRES PER ACRE SERVED FOR VERY LARGE ONES. DIMENSIONS IN METRES.

Area served in acres.	Drain Section.	Slope of Drain Water Surface in centimetres per kilometre.												
		1	2	3	4	5	6	7	8	9	10	12	15	20
2,500	Bed width	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	1·0	1·0	1·0	1·0
	Depth .	1·6	1·4	1·2	1·1	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
5,000	Bed width	3·0	3·0	3·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0
	Depth .	1·9	1·5	1·4	1·6	1·5	1·4	1·3	1·3	1·2	1·2	1·1	1·1	1·0
7,500	Bed width	4·0	3·0	3·0	3·0	3·0	3·0	3·0	2·0	2·0	2·0	2·0	2·0	2·0
	Depth .	1·8	1·9	1·8	1·7	1·6	1·5	1·4	1·7	1·6	1·5	1·4	1·3	1·1
10,000	Bed width	5·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	2·0	2·0	2·0	2·0
	Depth .	1·9	1·8	2·0	1·9	1·8	1·8	1·7	1·6	1·5	1·7	1·6	1·5	1·3
15,000	Bed width	6·0	5·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	3·0	2·0
	Depth .	2·0	1·9	1·9	2·0	1·9	1·9	1·8	1·7	1·6	1·5	1·5	1·4	1·5
20,000	Bed width	6·0	5·0	5·0	4·0	4·0	4·0	4·0	3·0	3·0	3·0	3·0	3·0	3·0
	Depth .	2·2	2·1	2·0	2·1	2·0	1·9	1·8	1·9	1·8	1·7	1·6	1·5	1·4
30,000	Bed width	7·0	6·0	6·0	5·0	5·0	5·0	4·0	4·0	4·0	4·0	3·0	3·0	3·0
	Depth .	2·4	2·2	2·1	2·1	2·0	1·9	2·1	2·0	1·9	1·8	1·8	1·7	1·6
40,000	Bed width	8·0	7·0	7·0	6·0	6·0	5·0	5·0	4·0	4·0	4·0	3·0	3·0	3·0
	Depth .	2·6	2·3	2·2	2·1	2·0	2·0	1·9	2·0	2·0	1·9	2·0	1·9	1·8
50,000	Bed width	9·0	8·0	7·0	6·0	6·0	6·0	6·0	5·0	5·0	5·0	5·0	4·0	4·0
	Depth .	2·8	2·5	2·4	2·3	2·2	2·1	2·0	2·2	2·1	2·0	1·9	1·9	1·8
75,000	Bed width	10·0	9·0	8·0	7·0	7·0	7·0	7·0	6·0	6·0	6·0	6·0	5·0	5·0
	Depth .	3·0	2·7	2·5	2·4	2·3	2·3	2·2	2·3	2·2	2·1	2·0	2·0	1·9
100,000	Bed width	13·0	11·0	10·0	9·0	9·0	8·0	8·0	7·0	7·0	7·0	7·0	6·0	6·0
	Depth .	3·3	3·0	2·7	2·6	2·4	2·6	2·5	2·5	2·4	2·3	2·2	2·2	2·1
150,000	Bed width	16·0	13·0	11·0	10·0	10·0	10·0	9·0	8·0	8·0	8·0	8·0	7·0	7·0
	Depth .	3·7	3·3	3·1	3·1	3·0	2·9	2·9	2·8	2·7	2·6	2·5	2·5	2·3
200,000	Bed width	18·0	15·0	13·0	12·0	12·0	12·0	11·0	10·0	10·0	9·0	9·0	8·0	8·0
	Depth .	3·8	3·5	3·2	3·2	3·1	3·0	3·0	2·9	2·7	2·8	2·7	2·7	2·5
300,000	Bed width	20·0	18·0	16·0	14·0	14·0	14·0	13·0	13·0	11·1	10·0	10·0	10·0	10·0
	Depth .	4·0	3·6	3·6	3·5	3·4	3·2	3·2	3·1	3·0	3·1	3·0	2·9	2·5

Note.—All calculations made for side slopes of 1 to 1 for the water section."

CHAPTER XI.

BARRAGES.

124. **Barrages.**—It will readily be understood that a perennial canal taking its supply from a river is far more effective if a weir or barrage is thrown across the river just below the canal head. The barrage arrests the flow of the river, raises the water surface, and so enables the river to feed the canal at a much higher level than would otherwise be possible. The advantages are twofold: (1) The canal in summer is not dependent for its discharge on the level of water in the river, for, however much the level may fall on the downstream side of the barrage, the level on the upstream side may be maintained at the height for which the work was designed, so long as the supply of water in the river is equal to the discharging capacity of the canal. And if, owing to lack of water in the river, this level cannot be maintained at its full height, it may be maintained higher than it would be if there were no barrage. Indeed, under these conditions the canal can take the full supply of the river and allow none to pass the barrage. (2) The bed of the canal taking off from above the barrage may be considerably raised, and great economies made in the construction and maintenance of the canal itself. For suppose that the full summer supply in a canal is 3 metres and the minimum depth of water in the river 2 metres, without a barrage it would be necessary to make the bed of the canal 1 metre below the bed of the river. Now, if a barrage is constructed which can hold up 4 metres of water, and if even the river downstream of the barrage dries up, still the upstream water surface will be 4 metres above the river bed, and the bed of the canal may be made 1 metre above the bed of the river, and the canal will still have 3 metres depth of water in time of low supply.

Both temporary and permanent barrages are employed in Egypt. Temporary barrages are of two kinds. If the work is meant to raise the level of the water and allow a certain quantity to pass down the river, the material employed is rubble stone. If the work is meant to seal hermetically the river at its tail and make a barrier between the sea water on one side and fresh water on the other, the material employed is earth

protected by sand-bags and stakes. The temporary stone barrages are made of rubble pitching carefully tipped from boats into the river. The whole length and breadth of the platform is covered with about 1 metre of tipped stone, then the next layer of 50 centimetres is laid, and so on; this is done to avoid undue scour at any one spot. These barrages need very careful protection at the two flanks to secure them from the back action of the water. Frequent soundings are taken on the downstream side, in order to find out if any displacement of the stone is taking place. When the main platform is brought to a height of 50 centimetres below summer level of the river, a small bank of stone, 2 metres wide at top, 6 metres at bottom, and 2 metres high, is placed on the upstream edge of the platform, being gradually raised in 50-centimetre layers. The temporary barrage shown in fig. 150 has a platform 18 metres wide at top, 26 metres at bottom, and 3·5 metres high. If the supply of the river falls and leakage has to be stopped, coarse metalling is thrown on the upstream side, then finer metalling, and if no water at all is to pass the dam, earth is eventually thrown upstream of the metalling and the dam made water-tight. On the rise of the river the crest or bank is removed, and the floods pass over the platform without any perceptible afflux. On the Damietta branch of the Nile such dams have been put in on a length of 160 metres, damming the low-water channel of the branch. They have held up 1·50 metres in low Nile with a maximum discharge of 75 cubic metres per second passing over them. On one occasion, when the Nile supply was very deficient, the dam was made water-tight and held up 3·20 metres. In constructing these temporary dams on the Nile, the greatest head of water should be such that the maximum water pressure bears to the submerged weight of the rubble a proportion of 1 to 40 or 50.

Such dams on the Damietta branch need 10,000 cubic metres of stone, and cost as a first charge £5000. The platform, however, becomes cemented with mud, and is to all practical purposes a permanent work. The yearly removal before the flood of the stone crest, and its renewal at the beginning of the summer, is a trifling and insignificant work.

The temporary earthen dams on the Damietta branch cost £6500, and on the Rosetta branch £10,500. Here the whole work is swept away by the flood and has to be renewed when needed.

We give (fig. 150) a cross section through one of the temporary barrages on the Damietta branch. Practically no water flowed over the top in summer, and the whole supply of the branch was turned down the canals between 1885 and 1889.

Fig. 151 gives the proposed strengthening of the existing barrage across the Euphrates at Hindia. With *good surface* masonry and a few stout blocks on the downstream side, it is extraordinary how strong a

rubble dam is, even with a very heavy discharge over the crest. It soon becomes cemented with sand and silt.

Fig. 150.

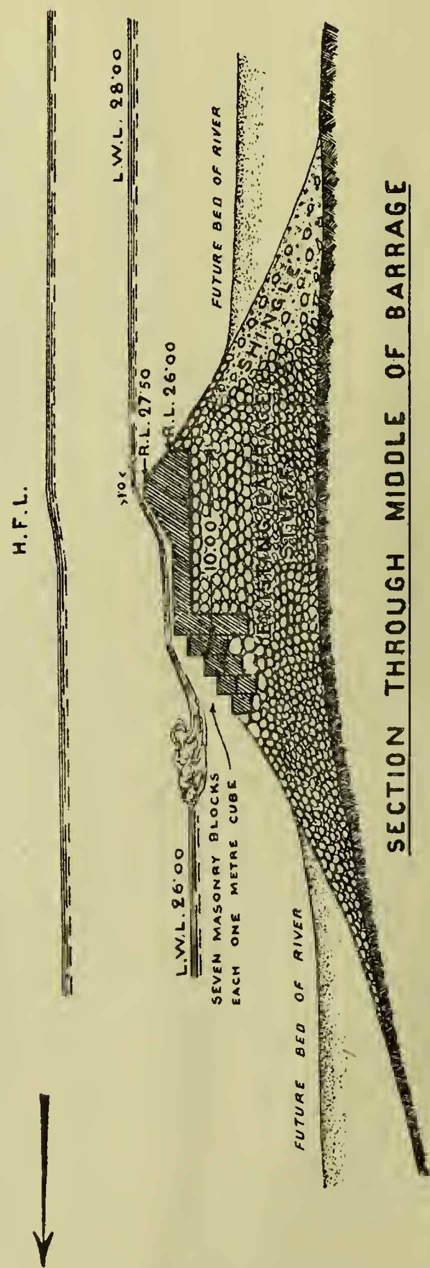
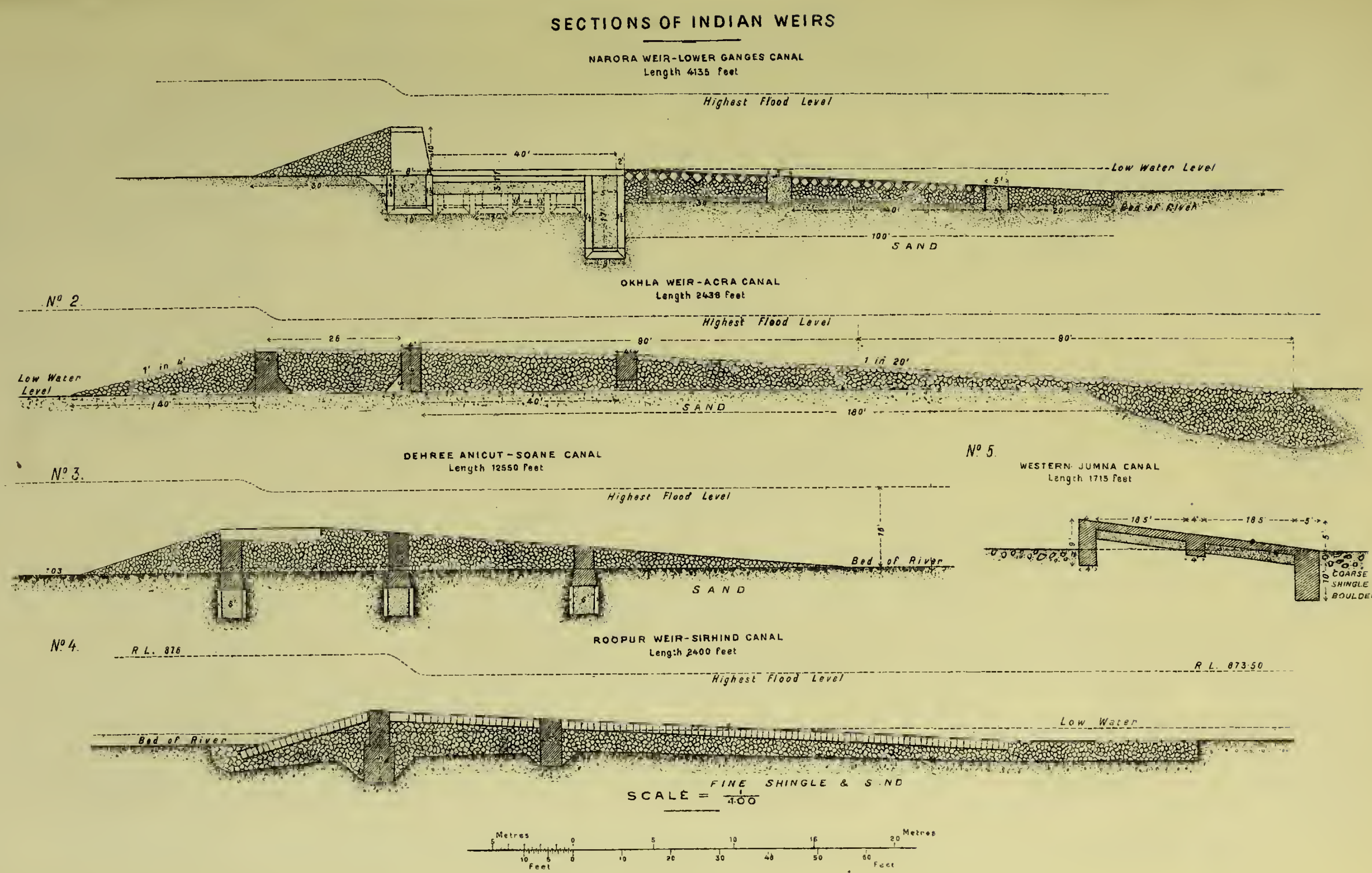


Fig. 151.—Proposed Strengthening of the Hindia Barrage on the Euphrates.

125. **The Delta Barrages.**—As these works are the first of their kind constructed in the world, they will be described in great detail. The



To face p. 632. Willcocks and Craig Egyptian Irrigation.

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permanent Barrages at the heads of the Rosetta and Damietta branches of the Nile are open dams, provided with openings along their entire length. Since the Nile in Egypt, during flood, is considerably above the level of the country, which is protected by dykes from inundation, it would have been dangerous to build a solid barrage which would have still further raised the water surface, unless a length of barrage could have been obtained much in excess of the normal width of the river. Plate LV. gives cross sections of some barrages in India (taken from Sir Hanbury Brown's report on the Zifta Barrage). It will be seen that most of the Indian barrages are solid ones. An afflux of 3 metres in summer corresponds to about 60 centimetres in flood on some of the Indian barrages.

As early as the beginning of the last century, Napoleon had spoken of the necessity of some regulation at the bifurcation of the Nile, in order to send the whole supply of the Nile first down one branch and then down the other, and thus double the inundation in flood: "Un jour viendra où l'on entreprendra un travail d'établissement de digues barrant les Branches de Damietta et de Rosetta au ventre de la bache [the bifurcation], ce qui, moyennant de batardeaux, permettra de laisser passer successivement toutes les eaux du Nil dans une branche ou dans l'autre, et de doubler ainsi l'inondation."

In 1833 Mohamed Ali Pasha, Viceroy of Egypt, finding it exceedingly difficult to clear the new summer canals sufficiently deep every year to receive the low level summer supply of the Nile, began closing the head of the Rosetta branch with an enormous stone dam in order to send the whole supply down the Damietta branch, which branch used to feed all the important canals. Linant Pasha induced the Viceroy to stop this rash proceeding, and proposed the construction of two barrages about 10 kilometres below the bifurcation, one on either branch. He proposed to build the barrages in the dry, and turn the Nile through them, closing the original channels with earthen embankments, opposite the new diversions. Mohamed Ali approved of the plan, and ordered the Pyramids to be dismantled and the stone removed to the barrages. When they proceeded to consider the method of demolition and transport, Linant Pasha proved to the satisfaction of the Viceroy that owing to the building of the Pyramid from the bottom upwards, it would be necessary to dismantle it from the top downwards, and consequently more costly than the opening of new limestone quarries on the bank of the Nile near Cairo; the Viceroy gave up the idea. The excavation of the foundations was well advanced, the workshops built, and the collection of materials in hand, when Mohamed Ali changed his mind and stopped the works. With the aid of the corvée he dug the main summer canals deep enough to dispense with the barrages, and for seven years, from 1835 to 1842, no more was

heard of the latter. In 1842 Mougel Bey arrived in Egypt, and recommended the present barrages and fortifications at the bifurcation itself. The idea of fortifications apparently pleased Mohamed Ali's military mind ; he conceived the idea of making the bifurcation the military capital of Egypt, and the works were immediately sanctioned and begun. Mohamed Ali died in 1848. By 1853 the works had not advanced sufficiently to please Abbas Pasha, the Viceroy, who dismissed Mougel Bey, and ordered a new man, Mazhar Bey, to finish the works on Mougel Bey's plans. The works were completed in 1861 at a cost of £1,880,000 exclusive of the corvée. The barrages, fortifications, canal heads, etc., are

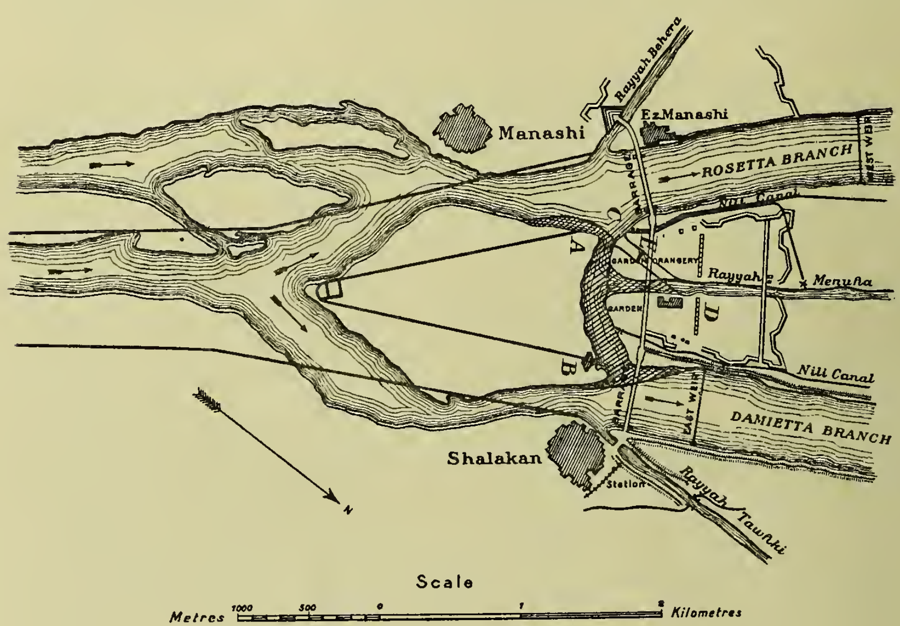


FIG. 152.—Plan of the Delta Barrages.

Note.—The channel from A to B has silted up. C D is the new head of the Rayah Menufia. E is the new regulator.

considered as having cost the country £4,000,000. Commissions of inquiry sat on the barrages in 1863, 1865, and 1867 ; their conclusions are embodied in Linant Pasha's memoirs. In 1863 they closed the Rosetta Barrage for the first time, but reopened it almost immediately afterwards owing to a settlement of part of the work. Later on, the method of repairing this settlement will be described, as well as the further history of the work.

Fig. 152 gives a block plan of the Barrages, while fig. 153 gives longitudinal and cross sections of the Rosetta branch Barrage. It will be seen that the Barrages are open dams across the heads of the Rosetta and Damietta branches of the river at the apex of the Delta proper. Of the two branches, the Rosetta has one and a half times the flood supply of the

other, while its bed is some 2 metres lower. The Rosetta Barrage is 465 metres between the flanks, and the Damietta one 535 metres. These

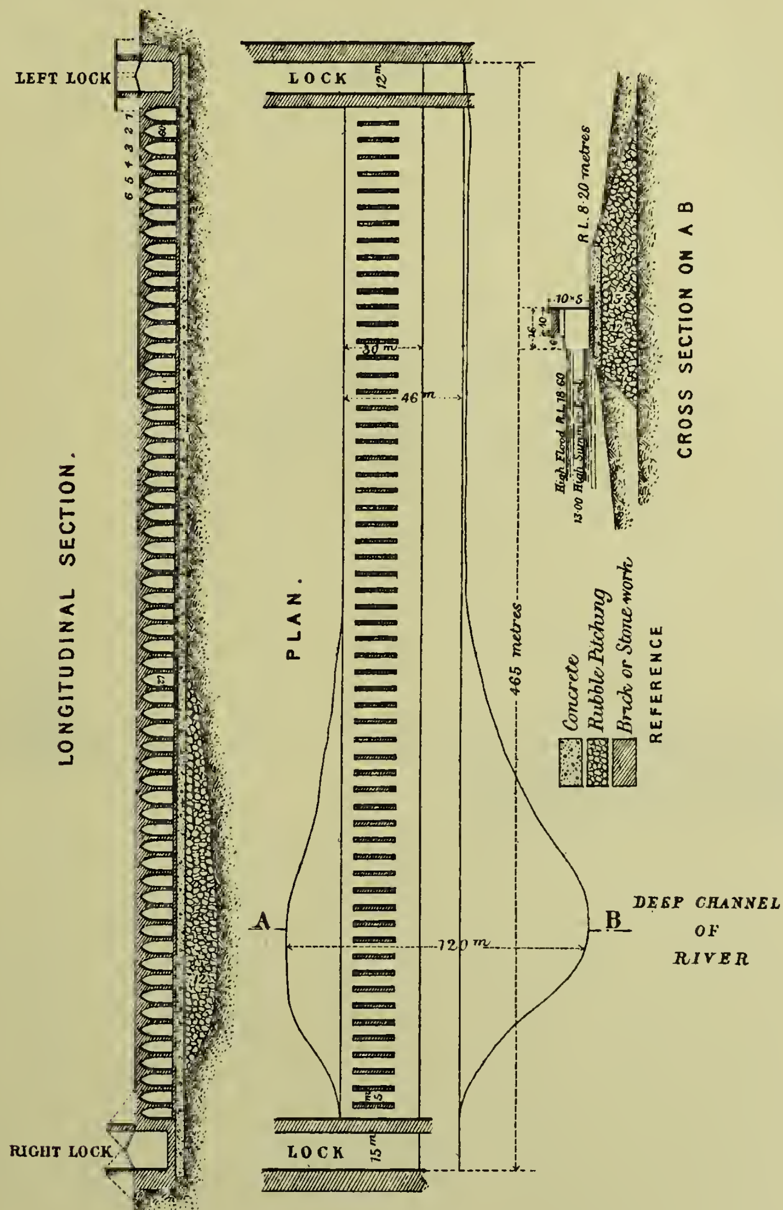


Fig. 153.—Rosetta Branch Barrage. Scale $\frac{1}{3000}$.

Barrages are separated by a revetment wall 1000 metres in length, in the middle of which is situated the head of the Rayah Menufia, or Menufia feeder, which feeds all the canals in the provinces of Menufia and Gharbia. The Rayah Behera, intended for the irrigation of the province of Behera,

has its head situated on the left bank of the Rosetta branch just upstream of the Barrage. The Rayah Tewfiki, intended for the irrigation of Sharkia and Dakahlia Provinces, has its head on the right bank of the Damietta branch, just upstream of the Barrage. These canals were intended to accomplish the whole summer irrigation of Lower Egypt, once the Barrages were repaired. Before the repairs (to be shortly mentioned) were executed between 1887 and 1890, the Barrages would have been thus described:—

"The platform * of the Rosetta Barrage is flush with the river bed, being 8·90 metres above mean sea, or 8·30 metres on the Barrage gauge. Its width

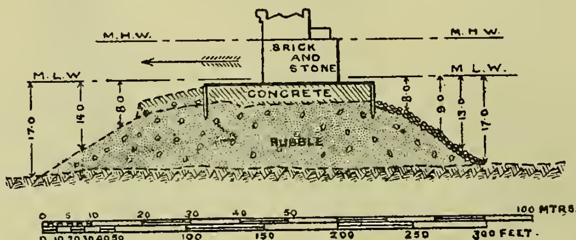
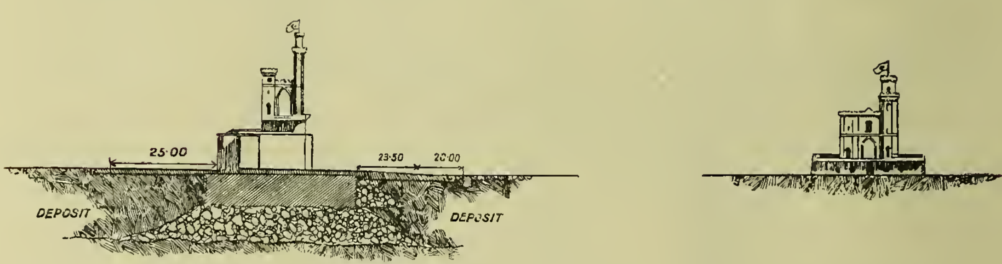


FIG. 154.—Cross Section of the Delta (Rosetta) Barrage, 1860.



Cross Section of the Delta Barrage. Elevation.

FIG. 155.

is 46 metres, and thickness 3·5 metres. It is composed of concrete overlaid by brick and stonework. Downstream of the platform was a talus of rubble pitching varying in places from 16 metres to 3 metres in depth, while its width was between 2 metres and 50 metres. The left half of the platform is laid on loose sand, the right half on a barrier of rubble pitching overlying the sand. This loose stone barrier is 10 metres high and 60 metres broad at the deepest part, and tapers off to zero at the ends. It closes the original deep channel of the river, and its only cementing material is the slime deposit of the Nile. This deposit has to all appearances made the platform water-tight. The platform supports a regulating bridge with a lock at either end. The bridge consists of 61 openings, each 5 metres wide; the lock on the left flank is 12 metres wide, while that on the right is 15 metres. Fifty-seven of the piers are 2 metres wide, while three of them are 3·50 metres wide each. Their height is 9·75 metres. The lock-walls are 3 and 4·75

* Taken almost verbatim from the *Min. Proc. Inst. C.E.*, vol. lxxxviii. part ii. Wherever the texts differ, the error is in the *Proceedings Inst. C.E.*

metres wide respectively. The piers support arches carrying a roadway. The two locks are provided with drawbridges. The concrete of the platform is inferior, while Mougel Bey condemns that under the ten openings from No. 5 to No. 14. The floor here settled some 10 centimetres during the floods of 1867, producing a deflection in the superstructure both horizontally and vertically. These ten openings were enclosed within a coffer-dam 5 metres high and 2 metres wide, composed of a wooden framework, filled with stiff clay, overlaid by stone, resting on the platform. Of the 61 openings, some are worked by means of the original iron gates 5 metres broad and 5·5 metres high, shaped like the arc of a circle, and supported at either end by iron rods radiating from the arc to the centre; here they are attached to massive iron collars working round cast-iron pivots embedded in the masonry of the piers at the centres of the arcs. It was originally intended to lower the gates by their own weight, and to raise them by pumping air into the hollow ribs, but the principle did not work. In place of this powerful crabs, travelling on rails at the roadway level, raise and lower the gates by means of chains attached to the bottoms of the gates. The openings unprovided with iron gates are closed by movable wooden verticals resting against horizontal iron girders fixed to a wooden frame within the grooves. The iron gates and wooden piles, when lowered, do not reach the platform of the Barrage; they rest on iron gratings 30 centimetres high, fixed into the piers just above the platform. These gratings allow of a free passage of the water when the gates are down. They were originally put in to prevent deposits of mud in front of the gates when shut.

The Damietta Barrage has ten openings more than the Rosetta Barrage, or seventy-one openings altogether. The platforms and superstructure are on the same level and exactly similar. No record exists of the state of foundations, but Mougel Bey states that the work here is good, since it was practically built in the dry. This Barrage was supplied with horizontals in 1884, and used for the first time; since the 15-metre lock was unprovided with gates, it was necessary to close it by a coffer-dam."

We now quote from the Second edition of this work:—

"Previous to 1884 the Barrages were regulated in the following manner: When the Nile gauge stood at 12·50 metres, which generally happened in March, the Rosetta Barrage gates and piles were quickly lowered to their full extent, beginning at opening No. 1 and closing at No. 61.* The consequence was a rapid current through the last openings just before they were closed. It was on one of these occasions that the ten openings from No. 5 to No. 14 were injured, according to the report of the Egyptian foreman on the work. The Government Report states that they were injured during the floods of 1867 owing to contracted waterway. As soon as the gates and piles reached the gratings, they could descend no further, and the work of regulation was at an end for that year. The upstream gauge rose to 13 metres, while the downstream gauge fell to 11·25 metres; so that, with a difference in water surface of 1·75 metres, there was a gain in water level of only ·50 metre. This was due to the fact that the Damietta Barrage was open. Of the water which escaped through the Rosetta Barrage, practically the whole found its way through the iron gratings. These gratings with a head of 1·75 metres, were capable of discharging 240 cubic metres per second. The river kept falling through

* The arches are numbered from west to east.

April, May, and June, and during the whole of this time the Damietta Barrage was open, as well as the gratings of the Rosetta Barrage. There was not sufficient water in the Nile to allow of a head of 1·75 metre on the latter, and it fell to 1 metre. Towards the end of June the up- and downstream gauges roughly indicated 12 metres and 11 metres respectively. If the Rosetta Barrage had failed in June, the loss of head in the Delta canals would have been ·35 metre. When the Nile began to rise in July, and the upstream gauge read 13 metres, the gates were raised as quickly as possible, the river fell to 12·50 metres, and was allowed to recover as the flood rose. This it did generally in six or eight days.

In November 1883 Sir Colin Scott-Moncrieff obtained the services of Mr (now Sir W.) Willcocks to undertake the utilisation of the Barrages. After an examination of the works in December 1883 and January 1884, it was decided to maintain above the Barrages a constant gauge of R.L. 13·00 metres. This resolve was supported by the following considerations:—

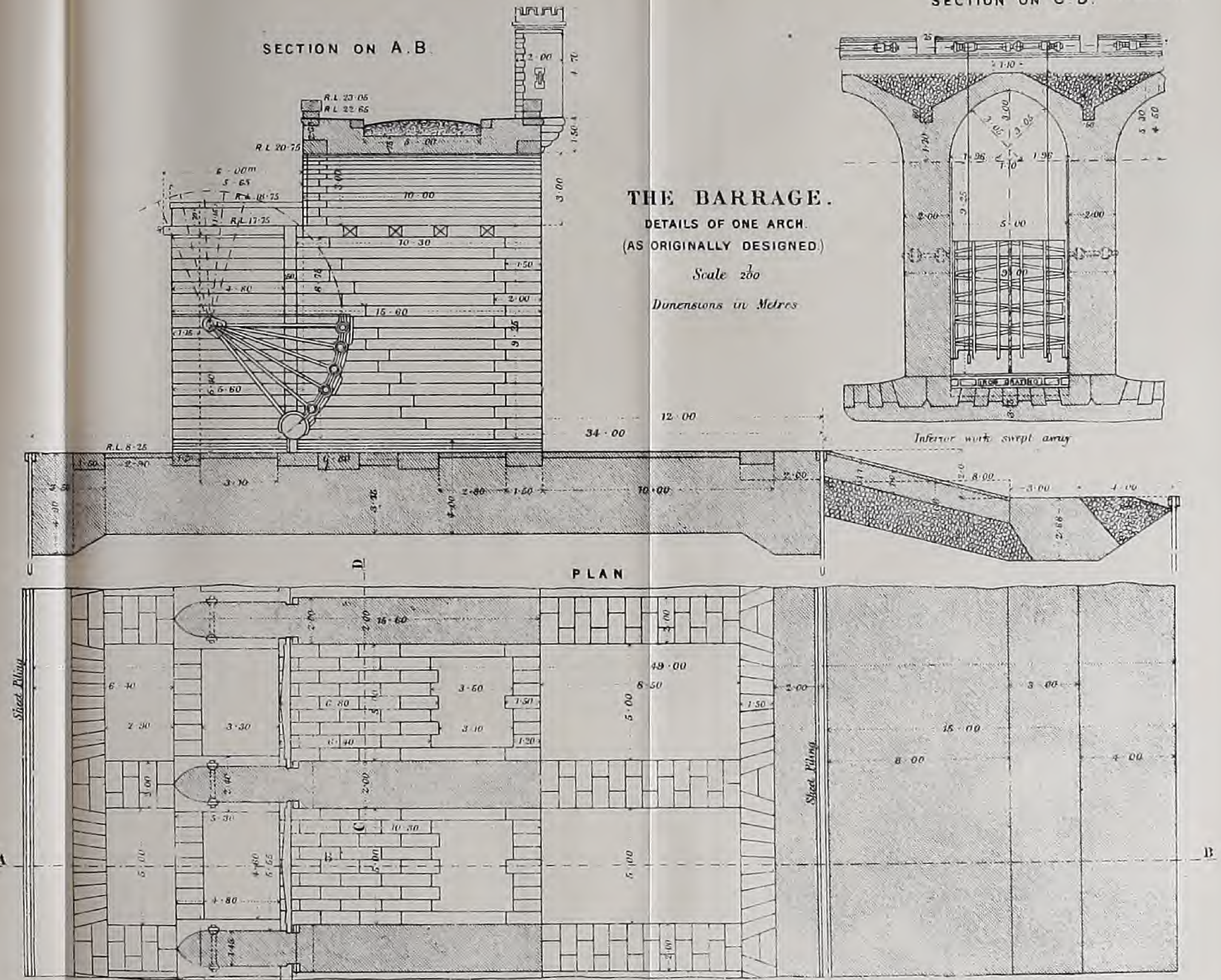
The studies of Sir John Fowler had proved that the brickwork on the surface of the platform was good, however inferior the concrete substructure might be.

The severe action below the Barrage when a gate was lowered to its full extent was found to be due to the iron gratings or 'windows' in the foundation, and not to a honeycombed foundation.

The Okhla dam at Delhi, on the river Jumna, a mass of loose rubble stone with absolutely no foundation, holds up yearly 3 metres of water, when the water pressure per lineal foot bears to the weight of the dam a proportion of $\frac{3125}{129,600}$, or $\frac{1}{40}$. Nile sand is finer than that in the Jumna, and will therefore require a lower coefficient; but this is a difference of degree and not of kind.

Considering the Barrage a thoroughly unsound work, and relying only on friction, it was determined to make the submerged weight of masonry bear a ratio of 50 to the pressure of the water going to be brought on it. Springs might cause a slight subsidence of any part of the Barrage, but it could not be moved as a whole. The pressure of a head of 3 metres of water would be 4500 kilograms per lineal metre. The submerged weight of the platform was 150,000 kilograms per lineal metre. The coefficient between them was $\frac{1}{33}$. That this proportion might be $\frac{1}{50}$ it was necessary to make the rubble talus everywhere 40 metres wide and 3 metres deep, with a submerged weight per lineal metre of 75,000 kilograms. This made the submerged platform and talus together 225,000 kilograms as compared to the pressure of 4500 kilograms. Since only one-third of the talus was completed in 1884, the Barrage was not required to hold up more than 2·2 metres of water; on the completion of the talus in 1885, 3 metres of water were held up. Plate LVI. gives the original section of the Barrage.

About the end of January 1884 the river gauge fell to 13 metres. From this date the gates and piles were gradually lowered in the Rosetta Barrage, so as to maintain this gauge. When the gates reached the gratings and the piles were driven home, the work of closing the gratings was taken in hand, while the talus was strengthened with 20,000 cubic metres of rubble pitching. Owing to the incomplete state of the talus, no more than 2·2 metres of water were held up on the Barrage. Attention was now directed to the Damietta Barrage, which was strengthened with 12,000 cubic metres of rubble pitching; the left flank lock was closed with a stone dam, the right lock was repaired and opened for navigation, and a channel for boats dredged to and from it; and all the openings were provided



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with oak horizontals and sheet-piles, and gradually closed. At this juncture Nubar Pasha, at Sir Colin Scott-Moncrieff's request, gave a special grant of £18,000

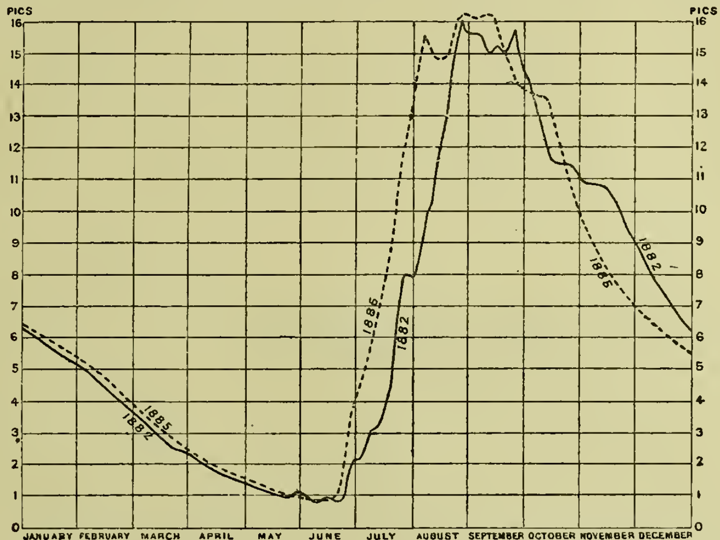


FIG. 156.—Aswan Gauge (Southern Boundary of Upper Egypt).
Scale 1 pic = 54·04 centimetres.

over and above the ordinary Budget, and so enabled the work to proceed without interruption. Eventually, at the end of the season, the Rosetta Barrage held up

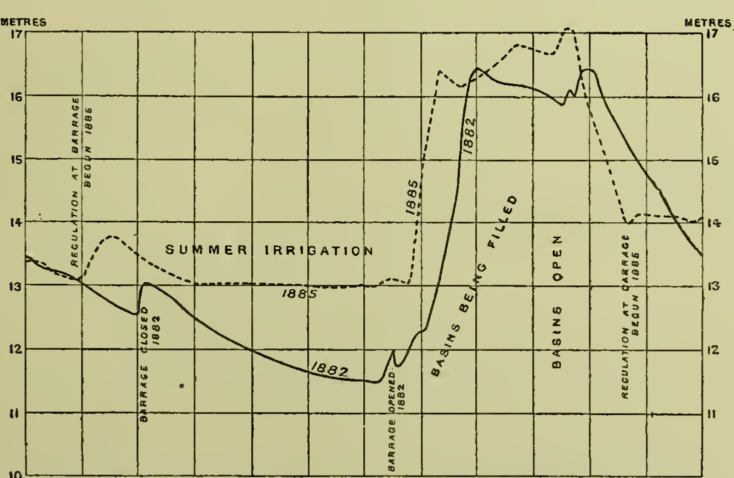


FIG. 157.—Barrage Gauge. Upstream.
Zero of Barrage Gauge 60 centimetres above mean sea.

2·2 metres and the Damietta 1 metre, while the water surface above the Barrages was 13 metres instead of 12 metres, as it would have been under the ordinary method of working. On the 7th of July the Nile began to rise, on the 13th of July the Damietta Barrage was opened, and the Rosetta between the 18th and 31st.

The Nile at Aswan during the summer of 1885 was lower than it had been in 1884, and almost similar to what it was in 1882.

During 1882 a discharge of 50 cubic metres per second entered the Rayah Menufia; during 1885 there was a uniform discharge of 120 cubic metres per second. This year the talus was completed with 34,000 cubic metres of rubble pitching, and a small temporary stone dam was raised on it, with its crest at reduced level 11·50 metres, so that the Barrage might hold up 1·5 metres, and the stone dam 1·5 metres, or 3 metres of water between them, the pressure being distributed. This dam was removed before the flood, and the materials were added to the talus.

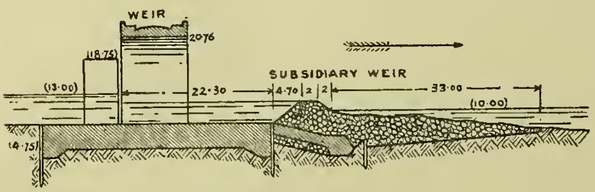


FIG. 158.—Cross Section of the Delta Barrage showing Strengthening of Talus, 1884–1887.

The wooden horizontals were found untrustworthy in both Barrages, and rolled iron beams were substituted. The coffer-dam round the ten weak openings was considerably strengthened. Eventually the Rosetta Barrage held up 3 metres and the Damietta Barrage 1·6 metres of water. The Nile began to rise on the 5th July, and the Barrages were completely opened by the 24th.

During 1886 Mr Perry, who had been resident engineer in 1884 and 1885, was put in charge of the Barrages, and worked on the same lines as in 1885, with the same results.

In 1887 Sir Colin Scott-Moncrieff put the Barrages under Colonel Western, C.M.G., and Mr A. Reid, C.M.G., of the construction branch of the Irrigation Department, and the repairs, to be described further on, were begun.

It will be interesting to record the method in which the Barrage was constructed. The following particulars were given by Mougel Bey himself:—

A level of 8·80 metres above the Mediterranean Sea (or 8·20 metres on the Barrage

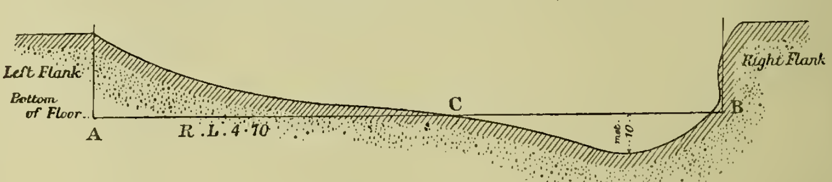


FIG. 159.

gauge) was fixed as the mean bed of the river at the bifurcation. The floor was to be 3·50 metres deep, and consequently a reduced level of 4·70 metres was the formation level of the bottom of the floor. Owing to the scour along the right bank of the Rosetta branch, the bed of the river was some 10 metres below this level at the deepest points; while on the left bank there was a considerable silt deposit above it.

The above represents a cross section of the Rosetta branch, at the site of the Barrage during construction, and the line AB the bottom of the floor: the part from A to C—where the floor is below the bed of the river—was first constructed. The sand was excavated as far as possible in the dry, and then two rows of sheet piling were driven down along the up- and downstream faces of the platform.

In the following cross section E F and G H are sheet piles within the sheet piling; the sand was dredged out down to R.L. 4·70 metres, and concrete skipped into the water, to its full thickness of 3 metres, and then allowed to set. Next season the sand was removed from above the concrete K L, and a coffer-dam M N was erected on the concrete, enclosing the space to be occupied by about five openings. The coffer-dam was filled with stiff clay, made water-tight, and the water was pumped out. The springs through the concrete were then staunched, the stone and brickwork floor O P laid over the concrete, and the piers raised to 1 metre above water level. The coffer-dam was then moved forward, and the space to be occupied by five new openings enclosed and treated in the same way. The sheet piling E F and G H was not cut down to floor level, but projected both up- and down-stream of the platform to a height of 1 metre above the floor. There seems to have been no difficulty experienced in this method of working, except under the arches numbered 7, 8, 9 and 10, near the left flank; here the sand was of a particularly fine quality, dark in colour, and very light, with the springs strongly impregnated with decayed organic matter. In spite of the dredger working in still water, the fine sand poured in fast from between the piles, and after being dredged was allowed to accumulate to a height of 8 metres and upwards, just outside the sheet piles. The more it accumulated the more the silt ran in, until the deepening of the trench became an impossibility. Mougel Bey wanted to postpone the work to the following year, but the Viceroy was urgent: men were crowded into the quicksand, the concrete skipped in, and the mixture of concrete and quicksand had to do duty for the floor. Mougel Bey says that the concrete there could not be more than 1·50 metres thick; Linant Pasha says that the springs here were always considerable, cracks appeared in the Barrages before any water was held up on the Barrage, and eventually this part of the Barrages failed and was surrounded by a coffer-dam.

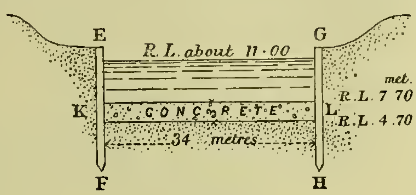


FIG. 160.

FIG. 161.

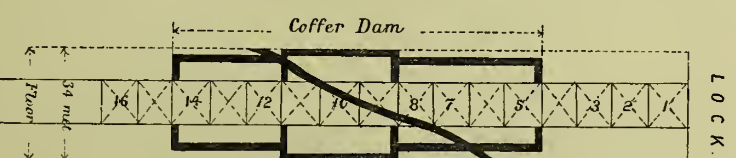


FIG. 162.

Referring to the cross section of the river, it will be seen that the construction of the Barrage along the part C B, where the floor lies higher than the bed of the

river, could not have been carried out as above. Here a mass of loose stone was pitched into the river from boats, until the upper surface of the tipped stone corresponded with the bottom of the platform, or the line A B. Into this barrier of stone, sheet piling (along the up- and downstream edges of the platform) was driven in as far as it could go. Sail cloth was laid on the upstream side of the piles, and held against the piles by the force of the current. The concrete was skipped into the water between the piles. Theoretically the tipped stone was at

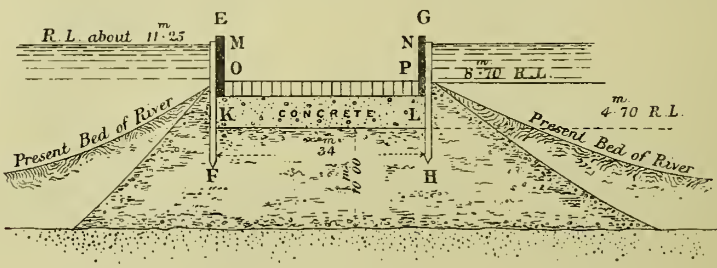


FIG. 163.

R.L. 4·70, but, practically, it must have been much lower, to allow of the extra concrete being skipped in here. As much of this concrete was skipped into running water, great part of the lime was washed away, according to Linant Pasha. Subsequently, when the coffer-dam was erected on the concrete for the completion of the floor and superstructure, the springs in places were so excessive that the floor level had to be raised 50 centimetres above the general level. The concrete was composed of broken stone, pure lime, and artificial puzzuolana in the ordinary proportions. Much of this concrete has not set, and in places has been found like pudding, though in others it is as hard as rock.

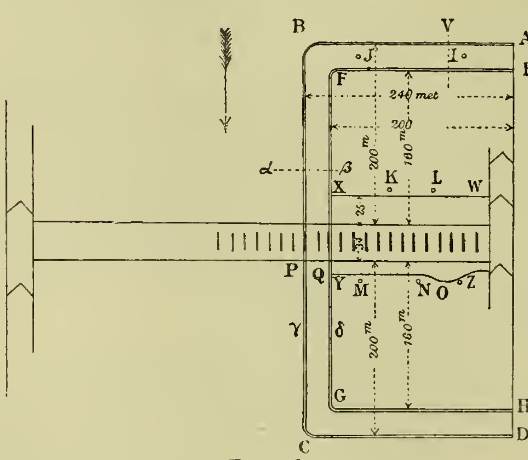


FIG. 164.

The Barrage repairs were begun in 1887 and completed in 1890.

A beginning was made with the left half of the Rosetta branch Barrage, which contained the injured openings. Two earthen dams, A, B, C, D, and E, F, G, H, were made round the left half of the Barrage, as shown in fig. 164.

Pumping stations at I and J kept the water at a low level between banks, and so relieved the springs in the work. X, Y, Z, W, is the area within which the repairs were executed, and K, L, M, N, O, were 10 and 12 horse-power portable engines, working centrifugal pumps which kept the foundations and work dry. The water from the pumps was carried in wooden troughs supported on trestles, which troughs threw it into the Nile, outside the banks. At α and β the deepest water was found, and the shallowest at γ and δ; the former section is represented in the

figure. Sand-bags,* costing £1000, were used in the construction of the earthen bank, which work was much facilitated by the closing of the Barrage gates throwing back water on the bank. At P and Q, where the dams were to pass over the pitching on the downstream side of the Barrage, channels were dredged through the pitching to allow the clay bank to rest on the original bed of the river. The sand within the area X, Y, Z, W, was excavated up to a R.L. of 9·20 metres, *i.e.* 1 metre above the floor, and the last metre in depth was taken out just in advance of new masonry. All repairs were *above* the level of the old floor, as will be seen from the sections. An upstream apron, 25 metres wide and 1·25 metres deep, of masonry was added to the Barrage; while the floor under the arches and on the downstream side was repaired according to its state and requirements, each opening being taken on its own merits.

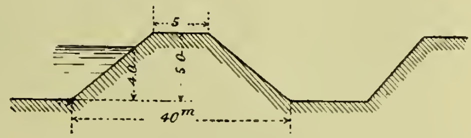


FIG. 165.

In the three following sections the first (fig. 166) is a section through arch No. 9, the worst of the series; the new work in this arch, and in number 10, was taken down to the old floor on a width of 1 metre only; up- and downstream of this metre

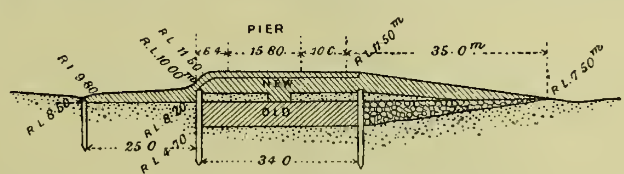


FIG. 166.

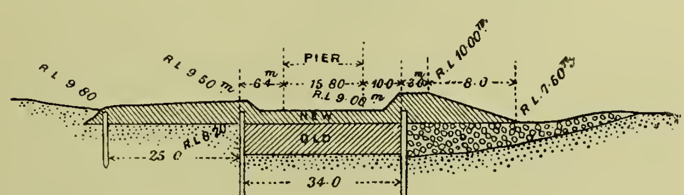


FIG. 167

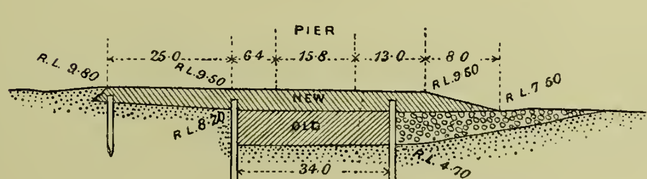


FIG. 168.

belt, the new work was laid on the sand which overlay the old work to a depth of some 50 centimetres. The springs here were very bad, and there were fears of the arches collapsing. The second and third sections (figs. 167 and 168) are through ordinary openings. (It was a fatal mistake for the original sheet piling to have

* Where wet clay was used the slopes of the bank under water were ½; where dry earth was used the slopes were ¼.

been left projecting about one metre above the floor. The water issuing through the openings shook the piles, disturbed the bed near them, and caused very violent springs along the sheet piling.) The springs under the arches near the settled work threw sand, and were not exposed, as explained above in the description of section No. 1; along the sheet piling the springs threw clear water.

The springs were closed in various ways, and two of the methods are given here in detail. If a spring burst out outside the old work, it was immediately covered with ballast, and, in finding its way through the ballast, in time ran quite clear. Springs along the sheet piling were closed either by vertical pipes or by horizontal ones.

1. (Vertical Pipes).—The spring was dug out to a depth of say 30 centimetres below the surface of the old masonry; and a vertical tube of from 5 to 10 or 15 centimetres diameter, according to the quantity of the water, was inserted. The

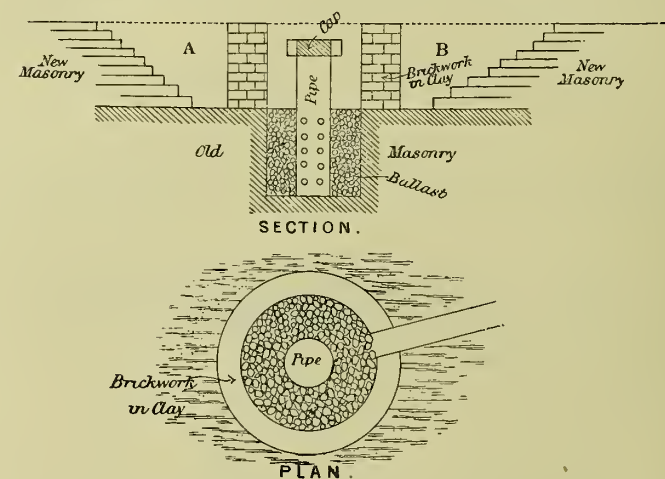


FIG. 169.

hole was then filled up with ballast round the tube. This tube was drilled with holes on the lower half of its length, while at the upper end were cut the threads of a screw, so that a cap might eventually be screwed on. Round the pipe, and removed about 10 centimetres from it, a ring of brickwork in stiff clay was built, open on one side; the cement masonry was then brought up from A and B till it was flush with the brickwork in stiff clay, and was allowed time to set. When set, the brickwork in clay was removed, and the space between the pipe and the cement masonry was filled up with cement mortar, or concrete or brickwork, an open space being still left on one side to allow the water coming up through the ballast to flow freely away. When the cement mortar had thoroughly set, and was strong enough to prevent springs working up through it, the opening was quickly shut up with dry cement and cement mortar, and weighed down, and the water began to flow freely through the top of the pipe. When the cement closing the opening had thoroughly set, the cap was screwed on the pipe and the whole built over.

2. (Horizontal Pipes).—The pipe in this case was drilled with holes on half the circumference of half the length, *i.e.* on a quarter of its surface, and was laid horizontally in a trench, with the holes over the spring, which had already had ballast strewn over it. The ballast was spread round half the pipe to the axis B C

(fig. 170). At E F a ring of brick in stiff clay was built round the pipe, and at D E cement masonry round the pipe. When the masonry at D E had set thoroughly, the brickwork in clay was removed and replaced by cement mortar or brickwork, while the space from B to C was covered with cement mortar and masonry, and the water allowed to flow down the pipe C B A Great care had to

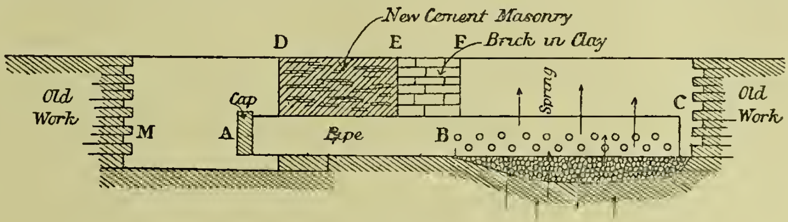


FIG. 170.

be taken that a hand-pump kept the water at M always lower than the top of the pipe, until the masonry above B C had thoroughly set. When the masonry had set the cap A was screwed on, and the whole space carefully built over in cement masonry. This system would be handy in a lock-gate recess. There were other methods of treating springs if they ran through a clearly defined orifice, such as

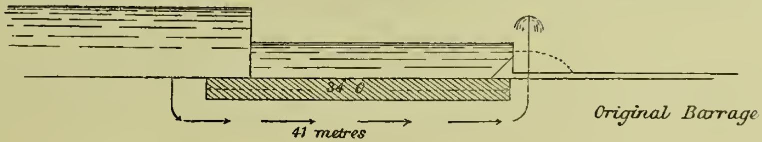


FIG. 171.

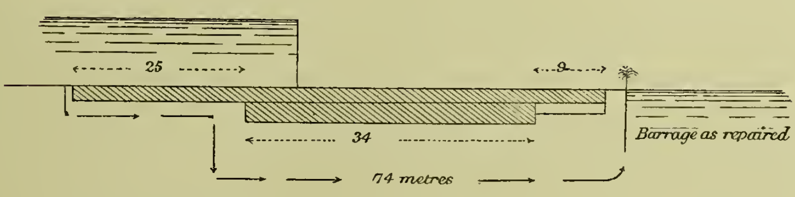


FIG. 172.

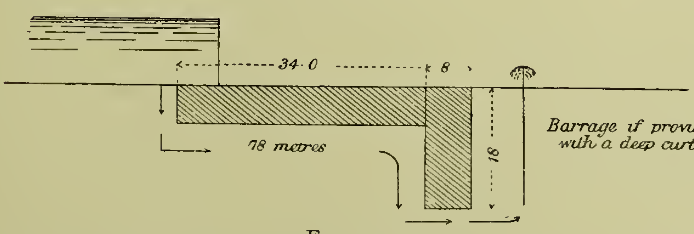


FIG. 173.

putting in a small bag full of dry linseed and letting it swell, and closing the spring, which could then be plastered over; or by cutting off the bottom of a bottle, putting it over a small spring, building round (taking care always to leave an opening till the cement had set), and eventually corking the bottle; but the two methods given in detail never disappointed, and can be strongly recommended. No attempt was made to force liquid cement down the pipes.

It will be noticed in the cross sections of the repaired Barrage floor that the

floor has been raised and lengthened, while no deep curtain wall has been provided. Sir John Fowler's borings near the Barrage had disclosed that the nature of the subsoil did not improve as one went deeper, and therefore nothing more was to be gained by a deep curtain wall beyond what could be gained by a horizontal extension of the floor. It was feared also that a deep curtain wall, taken down far below the bottom of the existing platform, might endanger the platform by disturbing the sand lying under it. By an extension of the floor, both up- and downstream, the points at which water enters the strata under the Barrage floor from the upstream side, and issues as springs on the downstream side, have been placed so far apart, that the resistance the water will meet with on this length will be sufficient to deprive it of the force necessary to move sand, and carry it away from under the work. The springs will issue clear, and be harmless. Figs. 171 to 173 explain the action of the springs and the distance they have to travel."

The following reports give the official descriptions of two seasons working out of the four. They were written by Mr Reid. The lucidity of Mr Reid's Reports kept pace with the excellence of his work. The directing spirit of the whole was Colonel Western, R.E., C.M.G. The advent of Colonel Western and Mr Reid marked an epoch in the history of irrigation works in Egypt. They came from India with ripe experience and an ability far above the ordinary. Masonry construction and regulation were lifted by them on to a higher plane.

"*Barrage Repairs*, 1887.—It having been decided to commence the work of repairing the Barrage by strengthening the floor of the left half of the Rosetta Bridge, the enclosure of that part of the stucture within earthen dams was begun on 2nd December 1886. The dams were double, the outer dam having been intended to act in the case of the inner one slipping. As the orders of the Public Works Ministry were to the effect that the water surface of the Barrage should be maintained at R.L. 13·00, if possible, and should never, except under pressure of threatened accident, fall below R.L. 12·80, the crests of these upstream dams were kept to a uniform level of 14·50. They were constructed in water varying in depth from 1½ metres near the shore to 5 metres in the middle of the river.

The downstream dams were brought to the level of 12·50 as the surface of the water was at R.L. 12·00 when they were made, and fell steadily to its summer level of 10 in April.

The dams were constructed in two months without any difficulty. The gates of the left half of the Barrage having been shut so as to reduce the flow of the water over the area to be enclosed, the two banks upstream and parallel to the Barrage were run forward for about 8 metres, by end-tipping, Bowles Portable Railway and Rolling Stock being used. At this point the current, setting diagonally towards the open half of the Barrage, and the draw caused by the leakage through the shutting of the closed half, prevented further progress being made in this manner. The completion of the outer dam was then pushed forward. At the end of the completed portion of the dam, a boat bridge 40 metres long was got into place, and a similar bridge was made 20 metres from the point at which the dam changed its direction and turned to meet the Barrage. These two bridges were finished

with a plank roadway 12 metres wide, and the bed of the river below them, and for 20 metres downstream, was floored with sand-bags to prevent deepening by scour. The portions of the dam between the ends of the two boat bridges, and between the outer bridge and the Barrage, were brought to water surface by dropping sand-bags along the alignment of its inner edge and backing with earth tipped from boats.

When the dams were so far completed, there remained only the gaps crossed by the boat bridges. These were 40 metres long and $1\frac{1}{2}$ metres deep, the current through them running about 1 metre per second. These gaps were closed by dropping sand-bags off the bridges, care being taken to raise the bottom of the gap uniformly, so as to have always a wide shallow stream in preference to a deep narrow shoot of water.

As the bottoms of the gaps were raised, the water inside the dam fell until there was a difference of level between upstream and downstream of 5 metres. The bags were then tied together in bundles of from 20 to 3, and the gap closed. In all, 41,000 bags, each holding 0·14 cubic metre, were used. They were ordinary grain bags, and when filled with earth were closed by sewing with twine.

Whilst the construction of the upstream dams was in progress, two cuts were dredged through the stone pitching downstream of the Barrage, so as to allow of the downstream dams being founded on soil, and therefore tight. The dredging was done by a $\frac{1}{2}$-cubic metre Priestman's dredger.

The outer upstream dam having been finished, the inner and downstream dams were made without any difficulty.

On 27th February the pumps were started, and by 4th March the clearing of the floor was commenced. The latter was the most laborious part of the whole season's work, as it embraced the removal of the coffer-dam enclosing the ten arches which had failed, and the clearing away of the stone bar which had been made along the downstream floor for the purpose of holding up the water surface during preceding years.

Work was commenced over the whole area and carried down to a level of $1\frac{1}{2}$ metres above floor.

Below that level the clearing was done over small areas only at a time, any area exposed being thoroughly cleaned and at once built on.

On 24th March the first stone of the repairs was laid under arch No. 4. On 2nd April, however, in attempting to lay the new floor upstream of the Barrage, and in the angle between it and the left lock, several springs broke out violently within 6 metres of the edge of the Barrage floor, and one very heavy spring broke out through the foundations of the lock wall. This wall was originally built by skipping concrete, composed of ordinary lime homra and broken stone, between two lines of sheet piling to a level 2·5 metres above the surface of the Barrage floor, the brickwork of the wall commencing at that level. The concrete appeared to have been skipped in very muddy water, and never to have set, as when part of a pile was sawed away, the concrete poured through the space so opened like rubbish shot out of a cart. The spring referred to came through the concrete and between the piles, bringing with it large quantities of very fine black mud.

During the day which was spent in getting in the new upstream apron and in carrying it up to cover the rotten piles of the lock wall, those piles bent forward about ·12 metre for a length of 20 metres; the concrete filling crushed down, and

the wall above, which was 8 metres high, cracked badly and leant over out of plumb.

By the evening it became apparent that further pumping would probably result in the fall of the lock wall, and the water was therefore allowed to rise 2 metres. At that height the springs ceased to throw mud, and owing to this and to the pressure of the water on the soil outside the foundations, a certain amount of stability was obtained and time thus gained for further work.

When pumping was discontinued, the ground had been cleared for the upstream apron for its full width of 25 metres and for a length of 30 metres.

About half this area had been covered with rubble masonry to an average thickness of 1 metre.

Concrete composed of 5 parts of broken stone, 1½ parts of desert sand, and 1 part of Portland cement, was then substituted for rubble masonry.

It was laid by tipping and treading down the tiphead. After two weeks, when the water was pumped down, the work was dug into and found to have well set.

The laying of the remainder of the apron gave no trouble. Springs occurred at a good many points, but they did not threaten the safety of the structure and they were all satisfactorily closed. Where the soil was of sand, the lower part of the apron was built of rubble masonry in mortar composed of 1½ pounded brick to 1 of lime. Where the soil was bad, the whole was made of rubble stone laid in mortar composed of 2 of sand to 1 of cement.

Concurrently with the laying of the apron, the repairs and additions to the existing floor were carried on. A great deal of difficulty was met with, owing to the ruinous state of the foundations of the bridge and to the tangled mass of rubbish of all sorts with which its floor was buried to the depth of 3 metres. The coffer-dam, enclosing arches Nos. 5 to 14 inclusive, had partly tumbled down. It had been originally very strongly constructed and largely braced with iron rods. These had bent, and were interlaced with timber, stones, chains, and every conceivable form of debris. The removal of almost every timber of this coffer-dam was followed by a squirt of water through the floor, and during its removal and the building of the new floor, the bridge itself cracked badly, evidence of considerable settlement.

The floors of the arches were raised to heights varying with the condition in which they were found to be. No. 9, which was the worst of all, was raised to R.L. 11·50. The springs under this arch were numerous and prevented the water being got down below 2 metres above floor. They were closed by the aid of iron pipes. The floor having been cleared of debris, silt, and rubbish as far as possible, ordinary cast-iron pump pipes 6 feet long were put into place, one vertically over each spring, and concrete was tipped to water-surface round them and over the whole area of the floor. Whilst this was being done, the water coming through the pipes was led away to the pumps in troughs and by channels previously prepared. When the concrete had set for six days, a trench 1 metre wide and extending from pier to pier was dug through the concrete down to floor level, a site having been chosen which was as far as could be judged sound. The floor was thoroughly cleaned, and the trench was then filled in with concrete laid in layers and rammed. The object of this was to make a water-tight diaphragm extend from the old to the new floor, and thus to prevent creep of water between the two. The pipes were then filled with finely broken concrete metal and closed by ¼-inch iron plates bolted on to their flanges, india-rubber packing rings being used to make the joint tight.

The whole floor was then concreted over to the necessary height and the ashlar face laid.

One 12-inch, one 10-inch, and two $4\frac{1}{2}$-inch pipes were used in closing the springs coming through the floor of this arch, and although all precaution was adopted, the arches cracked considerably during the progress of the work.

Arches Nos. 8 and 10 were also troublesome, the floor downstream of No. 10 being broken across diagonally in two separate lines—one of these lines was a crack for half its length widening out into a fissure 4 inches wide for a length of about 4 metres.

Where cracks of this sort occurred, they were staunched as follows:—The broken floor was cleared of debris bit by bit and covered at once with sand to a depth sufficient to keep down the springs. It was then surrounded at a distance by concrete laid after thorough clearing on the sound floor and carried up to a level at which the springs could not break through it. The concrete was then pushed on inwards until it was stopped by the flow of water. When this occurred the sand was carried away as deep as possible, and rubble masonry laid in cement mortar was built on the sand, a trench about 5 metres wide being left coinciding with the crack in the floor. Concrete metal was laid a few inches deep, and on it a pipe 2 metres longer than the crack, closed at one end and perforated with $\frac{1}{2}$-inch holes along its under half circumference for so much of its length as coincided with the crack, was securely built into the new masonry for its imperforate length.

An outflow drain was left in the masonry in the prolongation of the pipe, and the water from the broken floor was thus passed through the pipe to the pumps. When the masonry had set, the pipe was covered in with masonry laid in cement gauged neat, and the whole then raised to a safe height. The end of the pipe was afterwards closed with an iron plate and the outflow channel built up.

Upstream of arch No. 11 and between its cutwaters no floor appeared to have been built, as no trace of it could be found at 1·5 metres below its proper level.

The floor downstream of the Barrage was found to terminate at the distance of 12 metres from the bridge in a row of piling. Such drawings of the work as exist show a talus of concrete extending downstream of this piling, but in one or two places only could traces of it be found. The piling itself for almost its whole length projected from ·50 to 1·25 metres above the floor, and along its line numerous springs existed. The piles were all sawn off to the level of the floor and covered with rubble masonry $1\frac{1}{4}$ metres thick, this masonry being carried downstream to a distance of nowhere less than 7 metres.

Downstream of arches Nos. 12, 13, and 14, the floor was extended to a distance of 22 metres beyond the piling, and downstream of arches 7, 8, 9, 10, and 11 it was carried to a distance of 30 metres.

The left upstream lock was protected for its whole upstream length by an apron of rubble masonry 1 metre thick, sloping from R.L. 12·00 at the wall down to R.L. 10·00 at a distance of 12 metres, a toe 2 metres wide and 1 metre deep being given to the whole length.

Parallel to the Barrage, and at a distance of 20 metres from the upstream edge of its existing floor, a row of sheet piling was driven for a depth of 5 metres, the new floor being carried over it for a width of 5 metres.

Cast-iron grooves in which the new drop sluice gates will work were fitted to the piers.

The repairs to the floors of arches Nos. 1 to 29 inclusive were completed by 1st July, on which date work was stopped by the rise of the river.

In all, 5221 cubic metres of concrete, 12,985 cubic metres of rubble masonry, 412 cubic metres of Trieste stone ashlar, and 1491 cubic metres of Tura stone ashlar were laid. 133·6 cubic metres of piling were also driven.

The total expenditure on the work was £81,333.

The unwatering was done by six 12-inch centrifugal pumps, two 10-inch centrifugals, and one 9-inch pulsometer. An arrangement of a 4-inch pulsometer mounted on a truck with boiler and flexible suction was found to be very useful in unwatering small areas.

The work was carried on during the day without holidays from 2nd December 1886, to 28th March 1887. From the latter date to 1st July it was prosecuted without intermission. The lighting employed was electric, 8 arc lamps of 2000 candles power each being employed."

"*Barrage Repairs*, 1889.—The work done on the Barrage during the season of 1889 consisted of the repair of the floor of the eastern portion of the Rosetta, and of the fittings for gates on the eastern half of the Damietta.

On the Rosetta an exceptionally early fall of the Nile enabled work on the dams to be begun on 2nd November. This was extremely fortunate, as the depth of water was everywhere considerable, and for a distance of 100 metres it averaged 12 metres, reaching for a length of 25 metres to a depth of 15 metres.

On tipping the light soil which alone was available, it was found to take a very flat slope in the deep water, the bed of the river being appreciably raised at a distance of 100 metres from the centre line of the dam. As this resulted in great expense and loss of time, a pair of parallel banks was formed at 40 metres' distance from one another, between which the earth of the dam was afterwards tipped. The upstream of these banks was made of brick rubbish and spawls, and was carried up to R.L. 9·0, or 4 metres below water surface. The downstream bank was made of sand-bags, and was carried up to water level. In all, nearly 90,000 sacks were used on the dams.

The portion of the Barrage worked on was that founded on a bank of stone stated to be in one place 15 metres high. Some anxiety was felt whether this stone bank was silted up sufficiently to be as water-tight as the surrounding river bed, as if not, it would prevent the division of the area within the dams into separate ponds, and it might also, by allowing a free passage to the water lying at a low level, overpower the pumps. The bank, however, proved tight and no trouble resulted from its existence.

The dams embraced the whole of the unrepaired area of the Rosetta Barrage, consisting of thirty-nine arches and the east lock of 15 metres width. They were carried far enough to the west to enclose also four arches which had been repaired in 1887. This was done to enable any part of the unprotected end of the previous new work to be repaired should damage to it prove to have been caused by the two flood seasons which had passed since its construction.

The dam parallel to the axis of the river thus crossed the extensions to the original floor and the pitching at right angles. Downstream of the bridge the pitching was dredged away by two Kingston's dredgers to a depth at which, judging by the appearance of the stone brought up, it had silted solid.

On ultimately closing the dams and pumping out the enclosed area, the downstream dam proved perfectly tight, and throughout the work gave no trouble.

But the pitching crossed by the dam upstream of the bridge, being very small in sectional area, was not dredged away, and it was further believed that as it was remote from the draw of the Barrage it would have been silted up.

Such, however, did not prove to be the case, and on the water inside the dams being lowered, the dam began to slip on both its outer and inner faces. A spur of earthwork was run out from the dam, completely covering the pitching, and when this spur had reached a length of 25 metres the leak through the dam stopped and no further trouble ensued. For some hours, however, the dam was in serious danger; and as the date was 24th February, an accident would have caused greater loss than the mere cost of repair.

Owing to the great depth of water in which the upstream dam had to be constructed, it was determined not to make a second dam, but to trust entirely to one. As the level of the water upstream had to be kept to 13·00, and the pumping inside the dams carried down to R.L. 7·75, this single dam had to withstand a head of 5·25 metres, and this it did very satisfactorily for a period of four months.

On the completion of the outer dams the enclosed area was, as heretofore, divided into three ponds by banks parallel to the axis of the river, and on 24th February 1890 pumping was begun at 6 p.m.

The condition of the floor was found to be sounder than at any part of the Barrage previously taken up; but at the same time, owing to its having been exposed to the heaviest current of the river, its surface was more severely cut than at any other place. The brick facing was in many places cut completely through, and everywhere the surface was scored in lines 15 to 20 centimetres deep.

The usual evidences of careless treatment were found in the existence of deep holes and furrows cut by chains which, having fallen, had been allowed to remain on the floor. Unless in the future the Barrage is better worked than it has been in the past, serious damage will result. With the upstream gauge maintained to R.L. 14·00, the scour will be at times very heavy, and if a chain be allowed to vibrate on the floor it will bore a hole in a single month deep enough to seriously affect the safety of the bridge.

The work done was identical with that of previous years. The floor was raised to R.L. 9·0 everywhere except under nine arches. These nine were sound, but much cut, and as their surface was already at R.L. 8·60 in the centre and 8·85 at the piers, it was found advisable to put in the new work to R.L. 9·20, so as to obviate the necessity of cutting away any of the old floor in order to make room for the new ashlar facing. This enabled the invert to be levelled up with concrete to form a bed for the new masonry.

As stated above, the work done was similar to that of previous years, and consisted of the raising of the existing floor and its extension up- and downstream to the same distances as before. When this was completed, a line of blocks of masonry was placed along the toe of the work done in 1887.

To enable these blocks to be put in, a dam was run along the downstream floor for a length sufficient to allow of five or six blocks being built, and the usual enclosing dams were formed. The leakage of the gates was allowed to pass round each end of the dam on the floor, and the area enclosed by the dams was pumped out.

The excavation for the foundations of the blocks was a severe test of the

soundness of the work done in 1887, as the upstream gauge was maintained by the gates to R.L. 13·0, whilst the unwatering at the downstream edge of the apron was carried to R.L. 7·50; a head of 5·50 metres was thus put on to the work and no sign of weakness could be anywhere detected.

The total quantities of work done were :—

	Cubic metres.
Rubble masonry	12,499
Concrete	3,254
Trieste ashlar	319·2
Old Cairo ashlar	998·4
Brickwork	284

After the rise of the river, the fittings of the new gates were erected and the Rosetta Bridge completed. With the exception of the pitching, which must be added from year to year as necessity arises, the Rosetta Barrage is complete, and needs only careful and skilful regulating to prove a success. At the same time the soil on which the bridge is built is so feeble, the depth of the original foundations so slight, the weight of the superstructure so great, the pressure due to heading up so large, that any recklessness of treatment will be followed with disastrous effects."

After the completion of the repairs by Colonel Western and Mr Reid, the level of the water held up by the Barrages was raised in 1891 from R.L. 13·00 to R.L. 14·00 metres.

The following selections are from Sir Hanbury Brown's book on the Barrage, entitled *The History of the Barrage*, and published by Messrs Diemer, of Cairo :—

"The new system of regulation adopted in the restored Barrage consists of wrought-iron gates provided with rollers sliding in cast-iron grooves fixed in the piers. Since the maximum depth of water on the floor is 4½ metres (14½ feet), each opening has been given double grooves and two gates, of which the upper one is always 2½ metres high, and the lower one in the Damietta Barrage 2 metres. In the Rosetta Barrage the height of the bottom gate varies from 2½ to 1 metre in height, on account of the floor having been raised to different levels during the repairs. In one arch, No. 9, there is no bottom gate at all, the floor level being at R.L. 11·50. The top of the upper gates, when the Barrage is closed, is at R.L. 14·00, and of the lower gates at R.L. 11·50 throughout. The floor of the Damietta Barrage is at R.L. 9·50 in every archway : that of the Rosetta Barrage varies in different arches from R.L. 11·50 to 9·00.

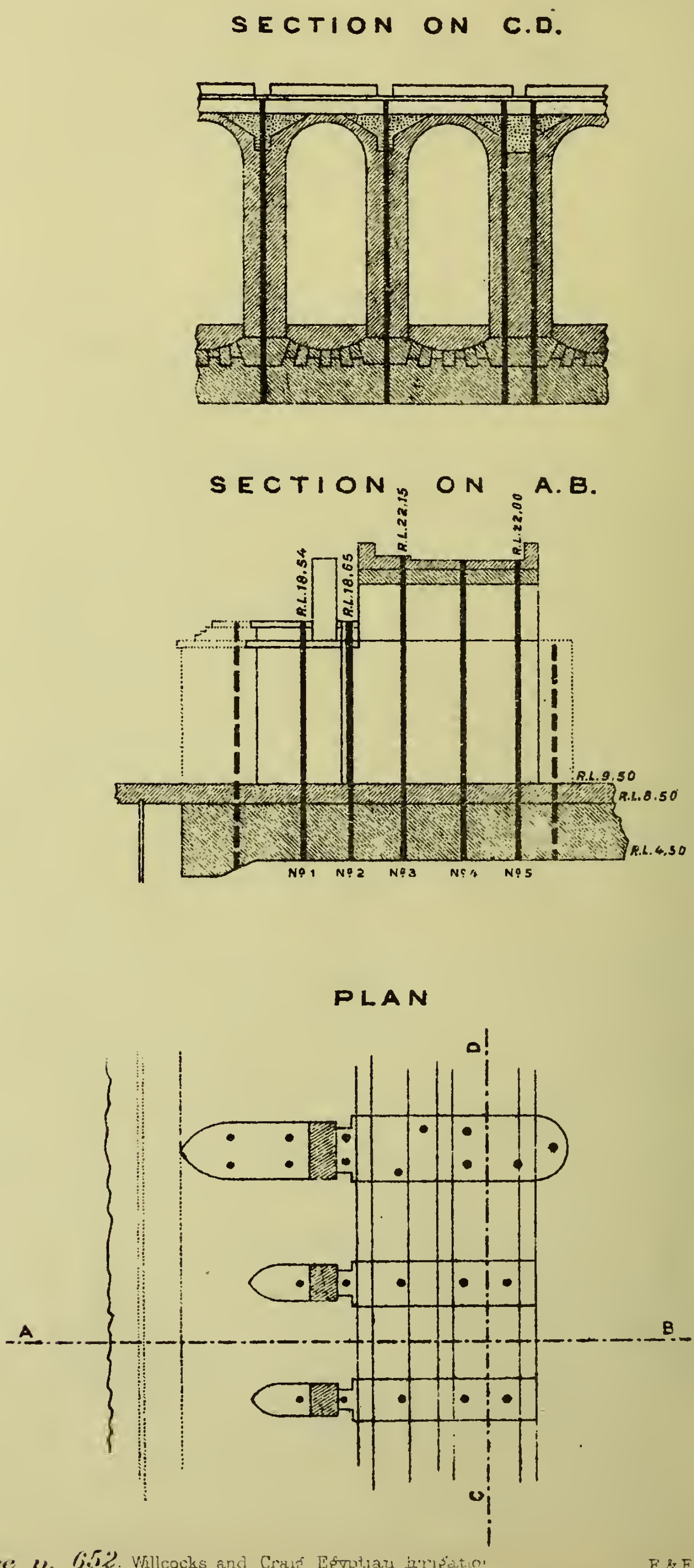
The gates are lowered and raised by means of powerful crab winches (of which there are two to each Barrage) travelling on continuous rails.

For record sake I give below the varying levels of the floor on the Rosetta Barrage.

	Metres.	
At R.L.	9·00.	No. 19 to 22, 24 to 25, 27 to 45, 55 to 61.
R.L.	9·20.	No. 46 to 54.
R.L.	9·50.	No. 1 to 6, 12 to 18, 23 and 26.
R.L.	10·00.	No. 7 and 11.
R.L.	10·50.	No. 8 and 10.
R.L.	11·50.	No. 9.

DIAGRAM

SHOWING BORES MADE IN THE BARRAGE PIERS.



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The arches, throughout this note, are numbered from west to east.
The total cost of this restoration for both Barrages was £465,000.
The quantities of masonry executed were :—

	Cubic metres.
Concrete	23,863
Rubble masonry	54,411
Ashlar masonry	6,983
Brick masonry	2,680
Dry rubble pitching	25,460
Total	113,397

In May 1891, when the Damietta Barrage was holding up 3·18 metres of water, seven springs appeared along the downstream edge of the masonry floor opposite bays 20, 21, 22, 25, 26, and 37; and it was ascertained by experiments that these springs arose from water which was passing under the floor from upstream of the Barrage. (It may be noted here that, according to rumour, this portion of the Damietta Barrage is founded on tipped stone like the right flank of the Rosetta Barrage.) A large inlet was discovered in front of bay 29–30. The inlet crater was filled with sacks of sand and an island of soil formed over it up to water level, and the upstream apron floor was also covered with soil. This weakened, but did not stop the springs, as the soil was too light, but further work had to be postponed till the next season.

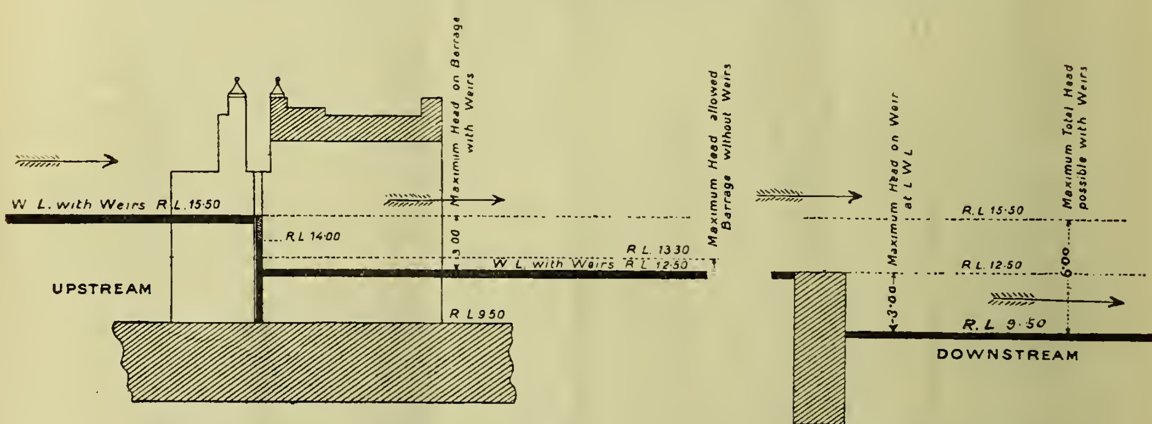
The following system for stopping the leaks was eventually adopted by Mr E. W. P. Foster, late Inspector-General of Irrigation in Lower Egypt. A trench, 20 metres wide and from 1·5 to 3·5 metres deep, was cleared of its rubble pitching and porous soil by dredging along the upstream edge of the floor in front of from three to five bays at a time. This trench was then filled with stiff clay deposited in layers of half a metre thick, pressed down by means of a sledge drawn over it, to form an impervious curtain. Over the junction between the clay and the masonry floor a broad clay bank one metre high was formed, and consolidated to make a tight joint: it was then covered with a layer of sacks filled with concrete and laid close together to protect the surface of the clay from erosion by the current. Great care had to be taken that this joint was properly cleared of loose material before the clay was laid on it, and that the concrete in sacks was carefully bedded and arranged. To do this a diving bell was made use of. Careful soundings made in 1895 over the whole area of concrete sacks showed that they had not been displaced by the flood."

Mr W. R. Kinipple, M.I.C E., who spent the winter of 1895 in Egypt, tried his method of stock ramming with clay to staunch the inferior substructure of the Barrages. It did not answer, but Sir Hanbury Brown employed cement grout in place of clay with marked success. Bore holes 12 centimetres in diameter were bored down through the piers to the bottom of the foundation. Plate LVII. gives the positions of the bore holes. Cement grout was poured in from the roadway level. This grout, under a pressure of 20 tons per square metre, was driven into all the interstices of the foundations. In places the grout travelled as far as 7 metres from one hole and rose up a neighbouring one.

This system of repairing foundations has very much to recommend it. Pages 46 to 50 of *The Delta Barrage*, by Sir Hanbury Brown, are good reading.

It has been stated that the Barrages were holding up to R.L. 14·00 metres in summer from 1891 onwards. In 1898 it was decided to raise the level to R.L. 15·50 metres. To gain this end, subsidiary weirs were built downstream of the two Barrages and the head divided as shown in fig. 174. These subsidiary weirs are similar to Indian weirs of the Okhla type. Plate LVIII. gives sections of them.

"It will be noted that there are expensive cement-grouted cores along the entire lengths of the works, taken down to a great depth. Sir Hanbury Brown considered



Barrage. Subsidiary Weir.

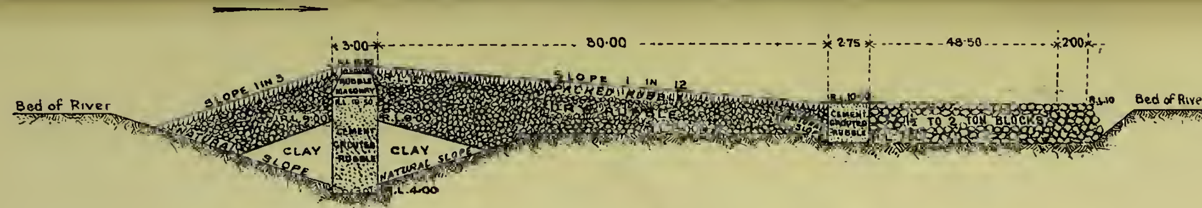
FIG. 174.—Longitudinal Section of the Delta Barrage and Subsidiary Weir showing Low Water Level.

the cores essential, as the subsidiary weirs had to retain 3·0 metres head of water when the weirs were tight shut and scarcely any water allowed to escape through. We are, however, of opinion that with weirs formed of rubble tipped into dredged channels and stock rammed with clay after Mr Kinipple's method along the entire length of the crest, the object of securing a water-tight structure would have been obtained at a fraction of the cost of the cement grouting. The upper 4 metres only need have been built of ordinary masonry along a width of 3 metres.

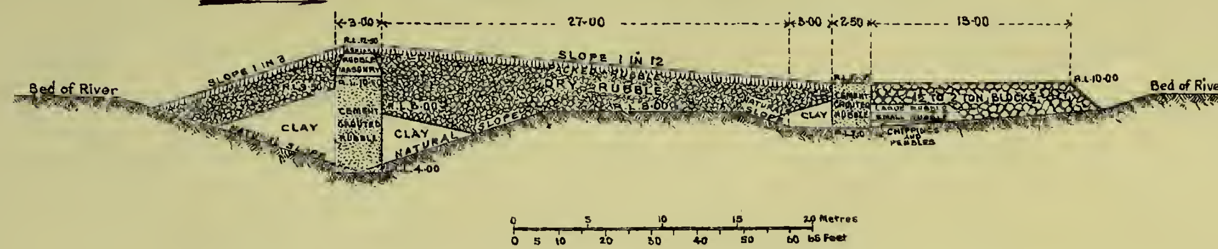
Plate LVIII. gives also, for comparison, a section of the subsidiary weir of the proposed Beled Barrage on the Tigris, to be built on shingle, taken from *The Irrigation of Mesopotamia.*

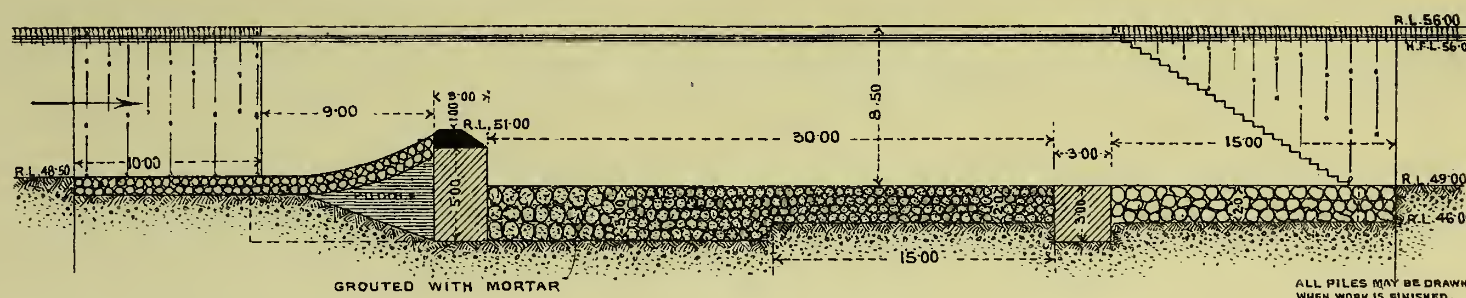
In constructing the subsidiary weirs of the Delta Barrages a trench was dredged along the line of the weir to the level of the bottom of the foundation. In this trench the water stood at a level of some 6 metres above the bottom. Into this pool of standing water was lowered a movable floating timber caisson, which was filled with rubble and grouted by means of cement grout poured down perforated iron pipes. As soon as a block had set, the caisson was moved on and the next block formed touching the one just completed; cracks between blocks owing to unequal settlement being themselves cement grouted. A very complete description of the

DAMIETTA SUBSIDIARY WEIR, 418 Metres Long.



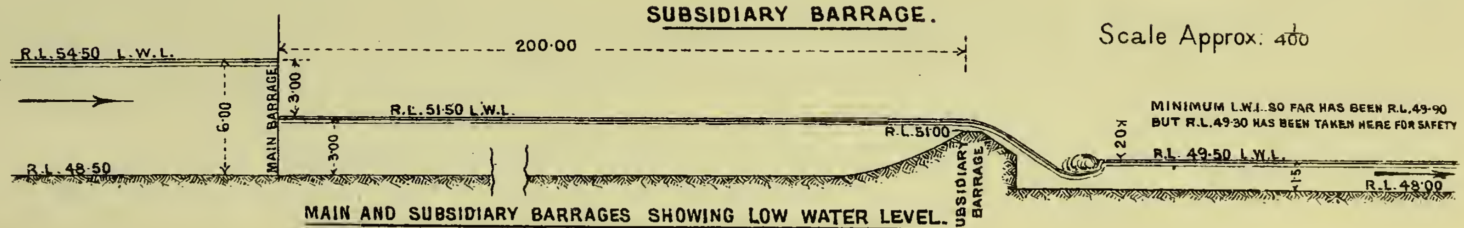
ROSETTA SUBSIDIARY WEIR, 500 Metres Long.





SUBSIDIARY BARRAGE.

Scale Approx: 1/400



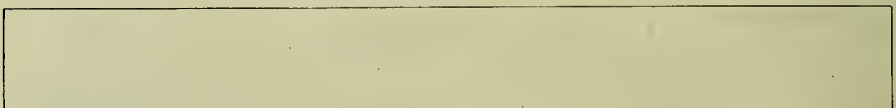
MAIN AND SUBSIDIARY BARRAGES SHOWING LOW WATER LEVEL.

PROPOSED BELED BARRAGES ON THE TIGRIS.

To face p. 654. Willcocks and Craig Egyptian Irrigation. E. & F. N. Spon Ltd London

The Delta Barrages, the Damietta Branch Barrage from Upstream.

Assiut Barrage (from Upstream).



Assiut Barrage (from Downstream).

method of procedure is given in *The Delta Barrage*, and in a paper read at the Institution of Civil Engineers by Sir R. Hanbury Brown, and entitled *The Use of Cement Grout at the Delta Barrage in Egypt.*

The subsidiary weirs, including the training of the river, adjustments of the lines of navigation, increasing the size of the regulating gates of the weirs, and provision of lock gates for two 12-metre wide locks, cost £450,000. The approximate amounts of work executed were:—

	Cubic metres.
Cement rubble masonry	51,000
Cement concrete	2,000
Rubble masonry in mortar	9,000
Brick masonry	10,000
Ashlar	2,600
Pitching	171,000
Ton blocks of stone	27,000
Clay	55,000

The subsidiary weirs aid the main Barrages in summer and at the beginning of the flood; but once the flood has established itself, the subsidiary weirs are completely drowned, and the main Barrages are alone capable of doing anything. As early as 1891 Colonel Western had said that he would regulate the Nile in flood as readily as in summer on the Delta Barrages strengthened as they had been by him. It was in the confident hope that such anticipation would one day be realised that this type of weir was selected as the one to be followed at Assiut when the work was designed in 1894. In 1899 Sir Hanbury Brown used the Delta Barrages through the flood. He was the first engineer actually to put his hand on the Nile flood, and to prove by demonstration that the greatest rivers in flood can be controlled by properly designed weirs, even when such works are floating on sand. By 1902 the confidence in the work had become so great that regulation went on as mechanically throughout the flood as it does every year through the summer. Such regulation once begun has become part of the life of the country, and can never be abandoned. It has become doubly necessary therefore that a very careful record should be kept of river soundings for 50 kilometres upstream of the Barrages and down both branches of the Nile to the sea. Every effort should be made, by occasional scours, to ensure the maintenance of the channels of the the rivers for the advent of the high floods. It has been found, with the aid of soundings conducted through a series of years, that a muddy river like the Nile in flood can, without any impediments whatever, raise its bed by a whole metre over hundreds of kilometres in length during a muddy and short flood, and scour out a metre below that level in a very high or a very long drawn-out flood."

126. **The Assiut Barrage.**—The Assiut Barrage is built across the Nile near the town of Assiut and just downstream of the Ibrahimia Canal head. Much of what follows is taken from an article written by one of us for *Public Works.*

The Ibrahimia Canal was the most important public work executed by Ismail Pasha when he was Khedive of Egypt. Designed primarily to provide perennial irrigation to the Khedivial sugar estates in Middle Egypt,

it supplied perennial irrigation to 580,000 acres and flood irrigation to another 420,000 acres. The discharge of the canal varied between 30 and 80 cubic metres per second in summer and between 500 and 900 cubic metres per second in flood. Having its head on the left bank of the Nile, opposite Assiut, it runs northwards for 60 kilometres and then divides into two main branches ; one branch is the Yusufi Canal, while the other is the Ibrahimia Canal proper. The Ibrahimia Canal, which is undoubtedly one of the largest artificial canals in the world, used to take off from the Nile without any weirs on the river. Its silt clearance and general maintenance were matters of supreme importance, as so much of Middle Egypt depended on it. Indeed, the surplus waters of the Ibrahimia Canal have always been utilised to complete the basin irrigation of the whole left bank of the Nile up to Cairo in years of low flood.

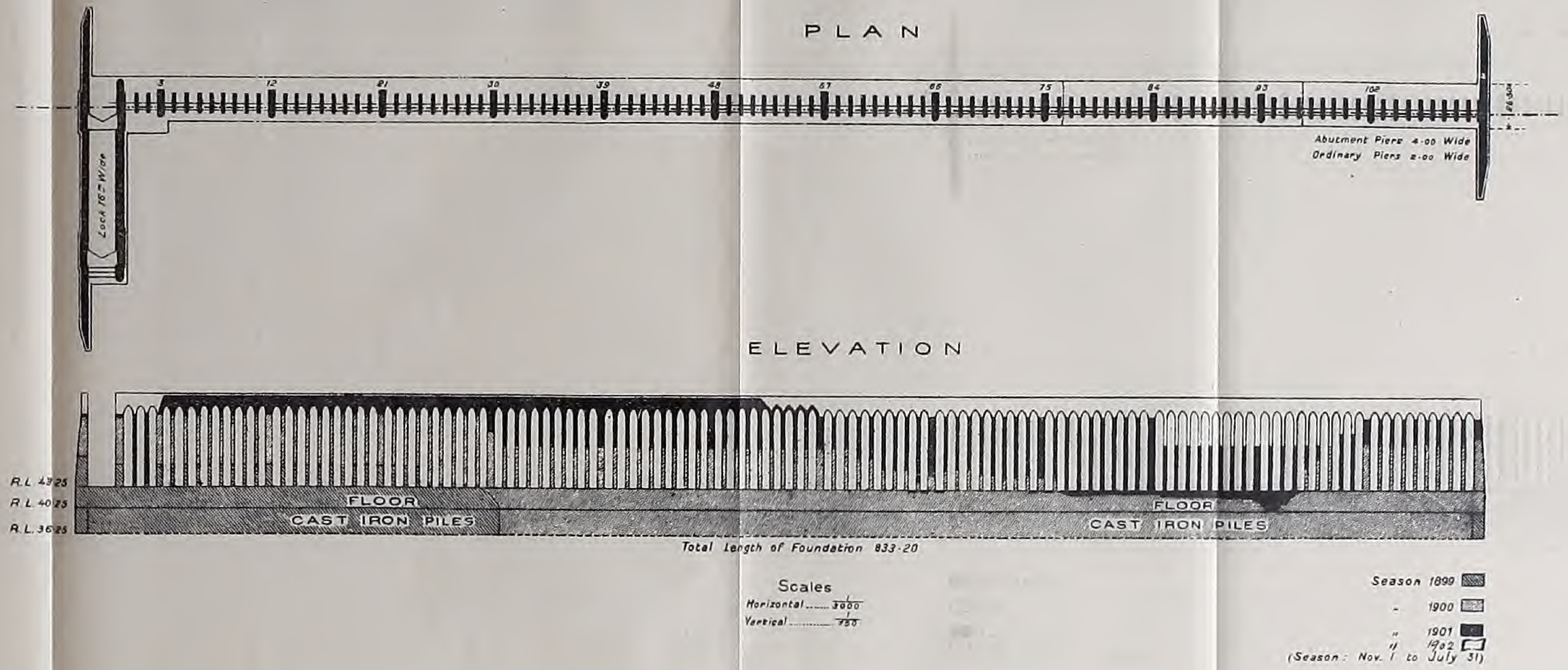
In connection with the project for the Aswan dam, it became necessary to provide the Nile with a weir at Assiut, to ensure to Middle Egypt its share of the reservoir water in summer. Sir William Garstin directed Mr (now Sir W.) Willcocks to prepare a project for a weir on the Nile at Assiut, and a regulating head for the Ibrahimia Canal. The works were to allow the Nile to carry its maximum supply past Assiut without any appreciable rise of level, while the Ibrahimia Canal was to provide sufficient perennial irrigation for the whole of Middle Egypt, or for 1,250,000 acres. It was calculated that 12,000 cubic metres per second was the maximum discharge of the Nile downstream of the Ibrahimia Canal head ; and that the Ibrahimia Canal, on account of its length, should be allowed 50 per cent. in excess of its theoretical flood discharge. This meant for the canal a discharge of $\left(\frac{1,250,000}{3000} + 50 \text{ per cent.}\right)$ or (420+210), or 630 cubic metres per second in flood. The summer discharge was assumed to be 140 cubic metres per second.

The data obtained at the site were the following :—

	Metres.
Ground level	R.L. 53·00 above mean sea.
High flood level	R.L. 53·95 ,, ,,
Mean low water level	R.L. 45·90 ,, ,,
Mean bed of the Nile . . .	R.L. 43·75 ,, ,,

Allowing for a depth of water of 10 metres in flood and a velocity of 2 metres per second through the openings, there resulted a waterway of $\frac{12,000}{20}$, or 600 lineal metres, or 120 openings of 5 metres each with the floor of the bed at mean bed level of the river. Allowing a depth of 8 metres of water in the Ibrahimia Canal below the head, and a velocity of 2 metres per second, there resulted a waterway for the canal head of $\frac{630}{16}$ or 40 lineal metres, or eight openings of 5 metres each. Before the construction of the work, Sir William Garstin decided to retain 170,000 acres under basin

ASSIUT BARRAGE



To face p.656

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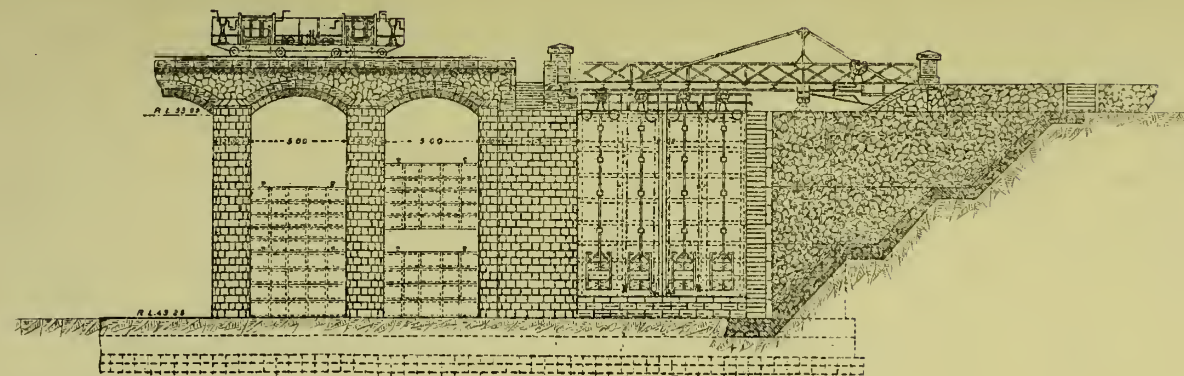
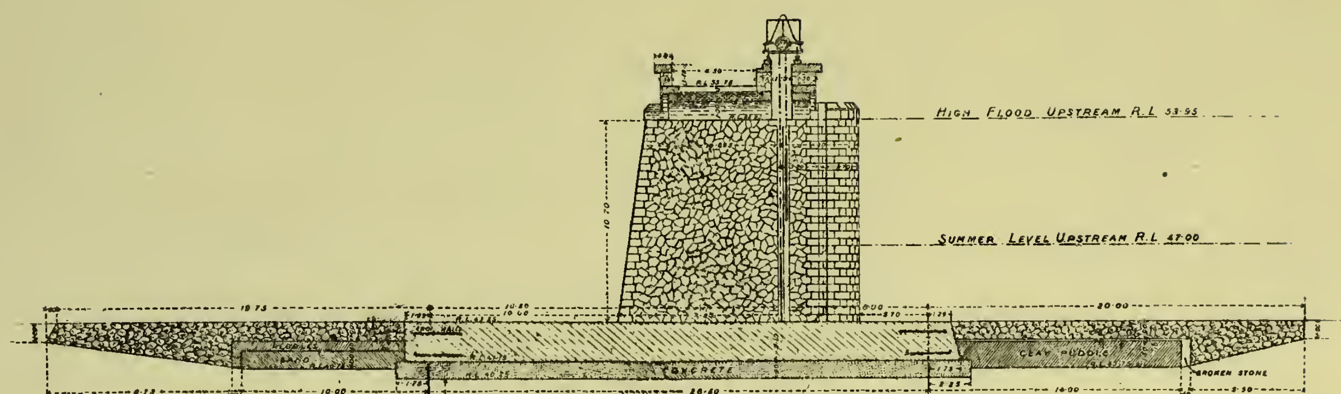
IBRAHIMIA CANAL HEAD REGULATOR, ASSIUT

SCALE $\frac{1}{400}$



UPSTREAM ELEVATION SHOWING UPPER GATES CLOSED



CROSS SECTION OF FLOOR AND SUPERSTRUCTURE

Scale: $\frac{1}{400}$

To face p. 650. Willcocks and Craig Egyptian Irrigation.

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irrigation, and provide perennial irrigation to 1,080,000 acres. This meant a discharge in the canal of $\left\{\left(\frac{1,080,000}{3000}+50 \text{ per cent.}\right)+\frac{170,000}{700}\right\}$ or 780 cubic metres per second; or an excess of 150 cubic metres per second in the canal and a corresponding decrease in the Nile. This meant 118 openings in the Nile and 10 openings in the canal head. Eventually the number of openings in the weir was reduced to 111, and the canal head openings increased to 9 in number. The canal head should have been given its 10 openings.

With the above data the design for the weir had to be chosen. Cross sections were made, to the same scale, of every important typical weir in the world. The Indian and Italian types were rejected, as they could not be worked in flood. The French weirs could be worked in flood, but the works were fairly at the end of their capacity in 6 metres depth of water, and could not be proposed for a river with 10 metres depth of water. The English weirs, as on the Manchester Ship Canal and in Ireland, allowed the water to escape under the gates, and not over the tops of the gates, and were consequently unsuited to rivers with sandy beds. There remained the Egyptian Delta Barrage, which answered every requirement. As this weir was a continuous series of undersluices from one flank to the other, a large number of typical undersluices were plotted to the same scale for comparison, and the conclusion was come to that the Delta Barrage undersluices, as remodelled by Lieut.-Col. Western and Mr Reid, had advantages over all the others. The 5-metre wide openings and 2-metre wide piers could not be beaten for proportion; while the fact that the openings were provided with double gates, over the tops of which the water escaped, was greatly in their favour for a work to be built across a river with a sandy bed. Sir William Garstin approved of the conclusions, and the works were designed in 1895. Plates LX., LXI., and LXII. enable the reader to obtain an excellent idea of the completed work.

A paper on *The Barrage across the Nile at Assiut* was read by Mr G. H. Stephens, at the Institution of Civil Engineers. The works as designed and as built will be now compared, since the principles underlying some of the modifications are of considerable general interest. The floor as designed was 2 metres thick under the openings and 4 metres under the piers, which were on circular wells. Mr Wilson, at the time of building, changed this into a uniform thickness of 3 metres. He did this after he had received a communication from Mr J. S. Beresford, C.S.I., Inspector-General of Irrigation in India, on the accident to the Narora weir on the Ganges River. According to Mr Beresford, the upward pressure at F in fig. 175 is measured by E G, where A G H is a continuation of the upstream water surface; and A B a straight line joining A, a point vertically above the upstream edge of the masonry floor at the level of the upstream water

surface, and B is a point vertically above the downstream edge of the masonry floor at the level of the downstream water surface. This change

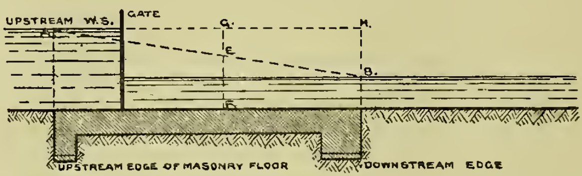


FIG. 175.—Diagram of Hydraulic Pressure, Assiut Barrage.

in the depth of the foundation introduced by Mr Wilson was a substantial improvement.

For further illustrations the reader is referred to Mr Stephens' paper, No. 3462, in the *Min. Proc. Inst. C.E.*, 1904.

The width of the foundation as designed was 26·50 metres with 2·54-metre wide walls as curtains, the upper curtain going down 4 metres below the floor, and the downstream curtain 5 metres. The floor as built has a width of 26·50 metres with cast-iron piles 7 metres long in place of the 2·50-metre wide curtains. At the Ibrahimia Canal head, which was built after the weir, the piles were supplemented with 2 metres of masonry, 3 metres deep, laid outside the piles.

In a river like the Nile, whose sandy bed is not so coarse as that of the Indian rivers, wells sunk after the Indian fashion would not have answered so well as the iron piles substituted by Sir Benjamin Baker. But better even than the heavy iron piles would have been steel piles of the Lackawanna type, which are easy indeed to handle and which need no cement grouting to make them water-tight.

The original design had 20 metres width of pitching downstream of the floor, of which 7 metres consisted of 3-metre cube masonry blocks, and the rest of ordinary pitching. If the finished work had contained treble this pitching, it would have been an improvement. The work as constructed had one-fourth of the pitching replaced by sand and pebbles, while the blocks were omitted. The sand and pebbles, which were expected to act as a filter for springs, might with advantage have been dribbled between the blocks of masonry and the pitching, and have thus formed a filtering medium without weakening the pitching.

The wing walls were designed at an angle of 135 degrees to lock wall and abutment, so that the water in flood might be led gently on to the works. The wing walls, as constructed, are in continuation of the lock wall and abutments, and the pitching takes off from them in hollow quadrants of 20 metres radius. This is an improvement on the downstream side, but the original design was infinitely better on the upstream side. Plate LXIII. shows up- and downstream wings as we think they should be designed.

In the original design the Ibrahimia Canal head lock was put on the left bank, *i.e.* the bank away from the weir, so that navigation might be easy in the gentler current on that bank. As built, the lock is on the right bank, just below the nose on which the river strikes. When the canal head is open in high flood navigation is impossible to-day.

The grooves for the Ibrahimia Canal head were designed like those on the Tewfiki Canal head, where both gates go down to the floor. The Assiut Barrage should also have been supplied with similar grooves and gates both going down to the floor. This has been rectified at the Esna Barrage.

The graceful pylon cornices of the original design have been replaced by blocks, which have a rugged beauty of their own, like that of English bull-dogs, but grace they have none.

TABLE 235.—QUANTITIES OF WORK, ASSIUT BARRAGE.

Items.		Quantities.		
		Barrage.	Canal Head.	Total.
Earthwork	cubic metres	1,401,000	434,000	1,835,000
Dredging	,,	300,000	200,000	500,000
Cement masonry	,,	79,400	15,000	94,400
Masonry	,,	54,000	11,300	65,300
Ashlar	,,	8,150	970	9,120
Pitching	,,	83,300	12,000	95,300
Clay puddle	,,	18,000	2,800	20,800
Metalling roadway	,,	1,500	500	2,000
Cast-iron pipes	tons	3,030	1,010	4,040
Regulating gates	square metres	2,750	225	2,975
Lock gates	,,	224	180	404
Swing bridge	lineal metres	16	9	25
Travelling winches	N°	4	1	5
Pumping cost in	£	90,000	17,500	107,500

The works were estimated to cost £525,000, but the budgetary provision was £800,000, or 50 per cent. in excess to provide for accidents and high floods sweeping away finished work and scouring holes. Fortunately, during the whole time of construction the floods were low. The finished works have cost £870,000. They were built by daily labour, the contractors receiving a percentage on their expenditure, and no exact account of each class of work can be given, as no detailed figures have been published. Messrs Aird & Co. were the contractors. They were represented on the works by Mr Hugh MacClure.

Some interesting selections are now given from the reports of the late Mr Wilson and Mr (now Sir A. L.) Webb, the Directors-General of Reservoirs, who carried out the works. Both officers had very exceptional knowledge of

the construction of weirs in sandy rivers. Mr G. H. Stephens was the resident engineer, and Mr Hood the senior assistant engineer.

Mr W. J. Wilson's Report for 1899.—"Sir Benjamin Baker, Consulting Engineer for the Works, proposed to drive sheet piling of cast iron up- and downstream of the weir, round the lock, and in front of the wing walls, and this system has been adopted. There is no doubt that the work has been carried out much more rapidly than it would have been with wells. The piles are driven 4 metres below the floor.

After enclosing a portion of the barrage foundation and that of the lock within an earthen bank tied on to the left bank of the Nile, pumping was commenced on the 19th February. Eight wells were sunk at different places up- and downstream of the actual line of the foundations, and the pumps were erected on them. Six of the wells were 2 metres, and two were 1·50 metres in diameter. They were sunk to R.L. 38·50, and were plugged with sand concrete—three of sand to one of cement deposited in skips; the plugs were ·70 metre thick. . . . Altogether eleven 12-inch pumps were used. The water was kept at between 25 and 40 centimetres below the tops of the piles. Three 6-inch pumps were then fixed to unwater the trench for the foundations between the piles, and the concrete was commenced.

Centrifugals worked by vertical direct-acting engines are the most suitable for this work. Two of them can be erected on a 2-metre well.

The cast-iron piles are very similar to some that have been used by Sir Alexander Rendel. They are tongued and grooved, but the grooves are 1⅛ inch longer than the tongues, which are 1½ inch. The space between the piles gets filled with sand. The sand is removed by pumping water down ½-inch pipe, which sinks into the grooves as the sand comes out. When the sand reaches the bottom of the pile, the pump is detached and cement grout is poured down the pipe. The cement when it sets makes a water-tight joint. This important modification in the design of the piles was due to Sir Benjamin Baker.

The iron piles were driven by steam pile engines working monkeys one ton in weight. To expedite the pile driving, the piles were driven in two stages, the forward engine driving them half way, and the following engine doing the rest. The two engines could drive seven piles a day, and eleven working night and day.*

The grouting of the joints is kept 10 metres back from the piles that are being driven, to prevent them from shaking.

When the foundation pit was unwatered, the top layer of loose mud was removed and the concrete laying begun. A few powerful springs developed and were taken up through the floor in pipes until the tops of the pipes were 7 metres above the floor. The temporary dams were cut on the 7th August, and after the water over the floor had reached the level of the channel of the river, cement grout was poured down the pipes to fill the cavities below the floor caused by the removal of sand by the springs. The pipes were broken off at the floor level after the cement had set.

To protect the end of the season's work in the event of the deep channel of

* With piles of the Lackawanna type, all this worry is quite done away with. The steel piles are light, easy to drive, fit perfectly, and give staunch joints. They can be driven in fifties per day. —THE AUTHORS.

the river changing and going over it, the end fifteen piles up- and downstream were made longer than the others; additional lengths of 16 feet were bolted on the lower lengths, and the combined pile of 32 feet in length was driven 3 metres deeper than the other piles. The tops of these long piles were then 2 metres below the level of the top of the floor, and the trench between the piles beyond the concrete was filled with sand-bags to the level of the tops of the piles. Mattresses of sand-bags roped together were continued beyond the piles and both up- and downstream of them."

Sir A. Webb's Report for 1900.—"Temporary dam-making was commenced on the west side on 23rd November, and on the east on 5th December.

Masonry in continuation of the previous season's work was commenced on the lock wall on 26th December, and on the piers on 10th January. By 10th January new temporary dams with the necessary pumps, enclosing a further length of 150 metres on the east side were completed.

Pile driving was commenced on the west side on 23rd January, and on the east side on 10th February.

The concreting of the lower part of the floor was commenced on the west side on 27th February, and on the east side on 19th March.

Work was continued under the highest pressure until 23rd July, when the rising flood unfortunately caused a breach in the temporary dams last made, thus stopping all further work. This accident occurred about five days before the date fixed for the termination of the season's work. All the pumps and machinery were recovered by the aid of divers, but some small loss of material had to be reported. The piles on the up- and downstream sides of the floor had been driven right across the river before the accident occurred, but a length of 20 metres of the floor remained wholly unbuilt, and a further length of 140 metres only partially built."

Sir A. Webb's Report for 1901.—"The main gap in the foundations, however, remained, and, in spite of all measures which were taken, it was found impossible to construct a water-tight dam across the finished work of the previous year; in every case the leakage through the pitching on the top and downstream of the floor was so great as to endanger the safety of the earthen dams as soon as the water in the enclosure was lowered. Finally it was decided to carry the dams right across the river and connect them with the eastern bank, necessitating the complete diversion of the main channel of the river. These earthen dams were completed on the 28th April and pumping commenced.

The total enclosures, extending over nearly one-half of the width of the whole river, covered an area of about $13\frac{1}{4}$ acres. Fifteen 12-inch, one 10-inch, one 8-inch, and one 6-inch pump were engaged in unwatering the foundations.

Owing to the presence of numerous and powerful springs, especially near the ends of the foundations previously built, great difficulty was experienced in laying the last piece of foundation. Special measures were, however, adopted; and to ensure that no voids existed under the new length of floor, a large portion of it, even where no springs of importance were encountered, was drilled with holes for grouting, from 3 to 4 metres apart, and cement grout forced down, whenever possible, through pipes standing up 5 metres above floor-level.

Prior to the laying of the last piece of foundation, a long length of the floor previously built on the east side was found to have been undermined from springs,

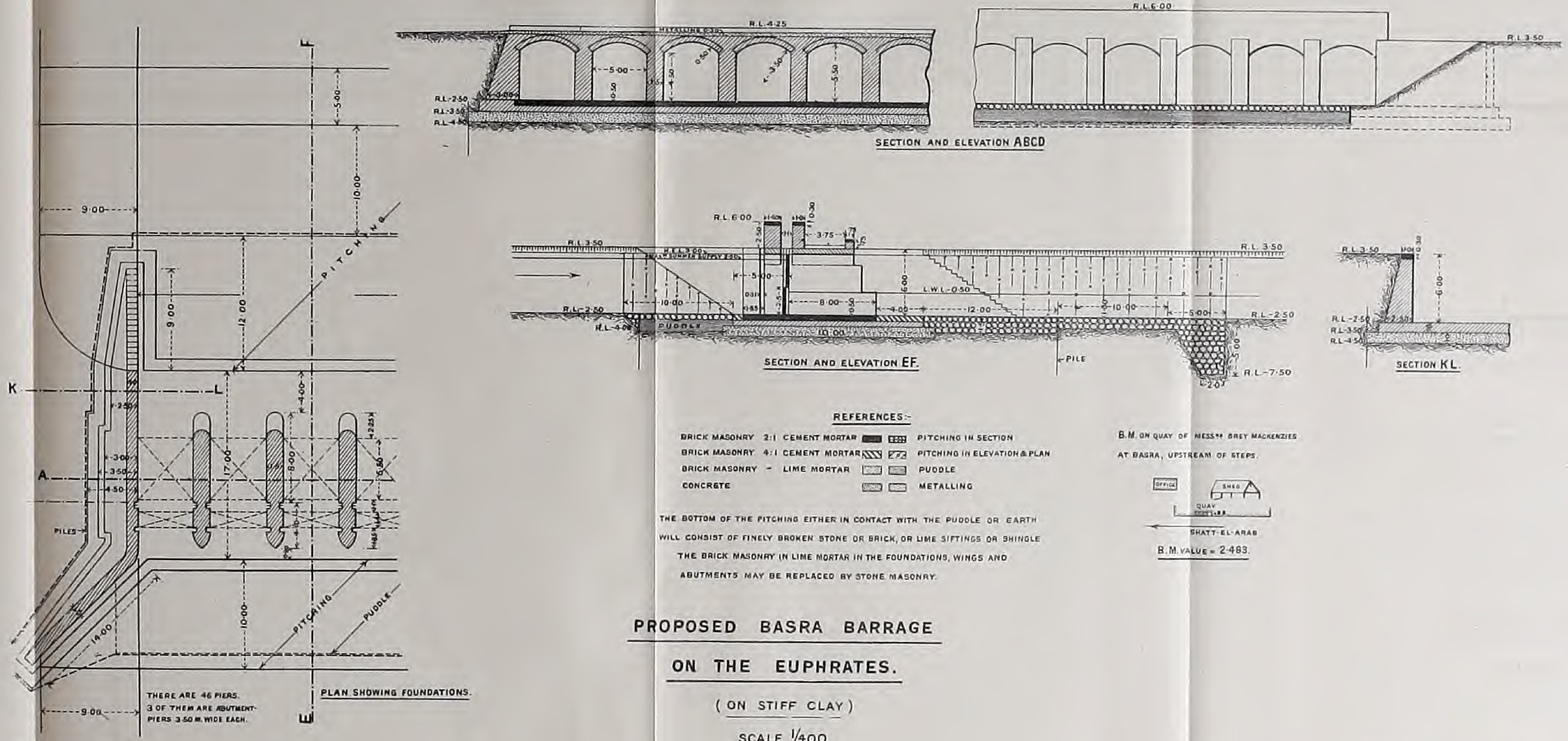
necessitating the grouting up of the same before much excavation work could be done, and this caused some delay in finishing the foundation.

On the 27th November 1900 the temporary diversion for maintaining the supply of the Ibrahimia Canal was commenced, and on the 13th February 1901 completed. Earthen dams were made across the existing channel up- and downstream of the site of the canal regulator, and the whole supply of the canal passed through the temporary diversion; these earthen dams were completed on 27th February, and the pumping and excavation for the foundations of the canal regulator immediately commenced. Eight 12-inch and one 8-inch pump were employed in unwatering the foundations, which were of the same nature as those of the barrage, and full of springs, of which 116 were dealt with.

Before the flood the work had been so vigorously carried on that the temporary diversion could be dammed off, and the flood supply of the canal passed through the regulator and lock. By the end of the year nearly the whole of the masonry had been completed both on the regulator and on the lock, but the ironwork had not arrived."

The successful completion of the work was principally due to the foresight and profound knowledge of the science of constructing weirs which the late Mr W. J. Wilson had acquired during many years' service in the Irrigation Department of Northern India. The lessons learnt on the Nile at Assiut have been utilised at Zifta and Esna.

The flood of 1902 more than justified the construction of this work. This flood was strangely low during the month of August. Indeed, all through August the country experienced the worst flood on record. The Ibrahimia Canal could not supply water at a level needed to irrigate the heavy maize crop of Middle Egypt, and prospects were dark indeed, when Sir A. L Webb proceeded to Assiut on the 15th August, and lowered all the gates into the sluices of the barrage only just completed. A 5-metre high obstruction in the Nile raised the flood level 1·50 metres, and every canal in Middle Egypt received its full flood supply from the Ibrahimia Canal. Lord Cromer, in his Report for 1902, calculated that the use of the Assiut Barrage in the manner indicated resulted in a gain to the country of £600,000 for that one single year. The work was one of considerable anxiety, for it has been explained that the Assiut Barrage was designed to meet the flood with all its gates down, while the Ibrahimia Canal was designed to meet the flood with all its gates up. As the flood rose the head of 1·50 metres fell to 1·30 metres. The discharge of 6000 cubic metres per second fell into what was practically a cistern 6 metres deep, increasing to 7 metres; and as the water passed over the tops of the gates, and not from under them, the action was confined in great part to the upper strata of water, which were considerably agitated for a distance of 150 metres downstream of the barrage. The pitching was quite inadequate. There was a reserve of 5000 cubic metres of pitching on the bank, while careful soundings of the floor were taken weekly by Mr



PROPOSED BASRA BARRAGE

ON THE EUPHRATES.

(ON STIFF CLAY)

SCALE 1/400.

To face p. 662 Willcocks and Craig Egyptian Irrigation.

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Lowe Brown, the resident engineer on the work. On the 18th September Mr Lowe Brown began throwing rubble into the localities where the pitching had settled, by means of a travelling gantry which permitted of the stones being thrown exactly where they were needed.

On the 19th September the head of water on the barrage was lowered to 50 centimetres, as the barrage had done its work and the retarded flood had at last come. Altogether 4000 cubic metres were thrown into 110 metres in length of the talus, or more stone than was originally put there. The river had flowed principally down two channels, one near the left flank and the other near the right, while there was a considerable silt deposit downstream of the barrage near the middle of the stream. The two channels, where the main currents were, and where the pitching settled, had severe backwaters on either side. It is the difference of depth of water which causes these deranging swirls of water, and a uniform depth can only be maintained by having a long stretch of really solid pitching downstream of the weir. After the experience of 1902, we are fairly confident that a barrage of the type of the one at Assiut, built on sand, could hold up 2 metres of water in full flood provided there was ample rubble pitching downstream. A vertical drop into a deep pool and a long stretch of pitching are all that is required. For the Nile we should recommend a floor as built, and then 10 metres of blocks, then 40 metres of 2-metre deep pitching, and then finally 10 metres of 7-metre deep pitching lowered into a dredged channel. This last is a suggestion of Mr Lowe Brown, and is a singularly happy one. After carefully inspecting Assiut, we went down to the Delta Barrage north of Cairo, where the fall was 1·70 metres on to a very strong apron of heavy pitching. The action was comparatively insignificant. Plate LXIII. gives a plan of the proposed Basra Barrage on the Euphrates, designed to hold up 2·50 metres on a clay bed, showing the deep pitching proposed downstream.

The following information has been kindly supplied to us by Mr G. T. Brooke, the Inspector:—

"Regulation is by means of two gates in each vent; each gate 2·50 metres high. Originally only one gate could be lowered to the floor, but in order to avoid regulation between gates the grooves were altered so that both gates could be lowered to the floor. The maximum head the Assiut Barrage is called upon to take occurs just before the imposing of summer rotations, *i.e.* in March, rising up to 2·30 metres head, the maximum recorded (29th March 1911, U.S. gauge 48·31; D.S. 46·01). This falls to about 1·35 metres as a minimum in May, and gradually rises with the increasing discharge to flood time.

R.L. 51·50 is required in the Ibrahimia Canal during the filling of the basins. The Assiut Barrage is accordingly regulated upon during flood to get as near this level as possible should the flood be a low one, and the barrage stands fully closed at times with the water passing over the tops of the gates—the tops of the gates

when so closed being at R.L. 48·25. But little damage is done to the D.S. apron owing to the facilities given by the double grooves and also by careful attention to distribution of the discharge evenly through the openings. The regulation is effected by 4 crab winches worked by hand.

A pocket having formed upstream of the eastern abutment, the revetted slope protecting the abutment is being extended by a rubble bar at right angles to the centre line of the barrage at its commencement and then following the desired bend of the river. At present this rubble bar is carried up to R.L. 48·00, and extends some 2 kilometres in length. The afflux on the barrage is 15 centimetres in full flood (53·95 U.S., and 53·80 D.S.)."

127. **The Zifta Barrage** was designed and built by Sir Hanbury Brown. We give a description of the work from his pen contained in the Irrigation Reports for 1901 and 1902.

We have already given on page 387 selections from his report containing reasons why the work was needed. These should be referred to. We continue :—

"The barrage is designed to hold up 4 metres of water. It has fifty openings of 5 metres width with abutment piers between each group of ten. The design is the same in its main features as the Assiut Barrage, with cast-iron piles of special form up- and downstream of the floor and round the lock. The piles along the upstream face are 16 feet long, while those along the downstream are 10 feet only, which is a departure from the Assiut design. The floor section of the Zifta Barrage is given on Plate LXIV.

The lock at the west end has a chamber 12 metres wide and 65 metres long, the same dimensions as the weir locks. It will be provided with a lift bridge for the road traffic between the two sides of the river, hitherto carried on by a ferry of the usual unregenerate village type.

The barrage with its lock may be expected to cost £350,000; and the subsidiary works, required to put the work into gear with the existing system of canals, will probably cost another £150,000. The cost of the land to be expropriated for the main connecting canals forms a very large item in the estimate, as it is some of the best in Egypt.

Though preparatory work was all that was at first contemplated for the first season's work, it was decided to make an effort to get in the lock foundations and about 50 metres length of the regulator floor, so that this portion of the work might be used in the second season for the passage of the river discharge while the rest of the foundations were being got in. The difficulty of getting a sufficient number of the cast-iron piles supplied in time made success doubtful. Only a limited number of piles could be manufactured in the country in the short time available, so the remainder had to be got out from England. The excavation of the foundations proved to be an easier work than had been expected, as, at foundation level, a stratum of stiff clay spread over two-thirds of the lock area and also over most of the length of regulator taken in hand.

The piles were supplied in good time, and the first pile was driven on 5th May 1901. Concreting in the lock floor was begun on 19th May. By the end of July the lock foundations and sills up to 5 metres height above foundation bed had been

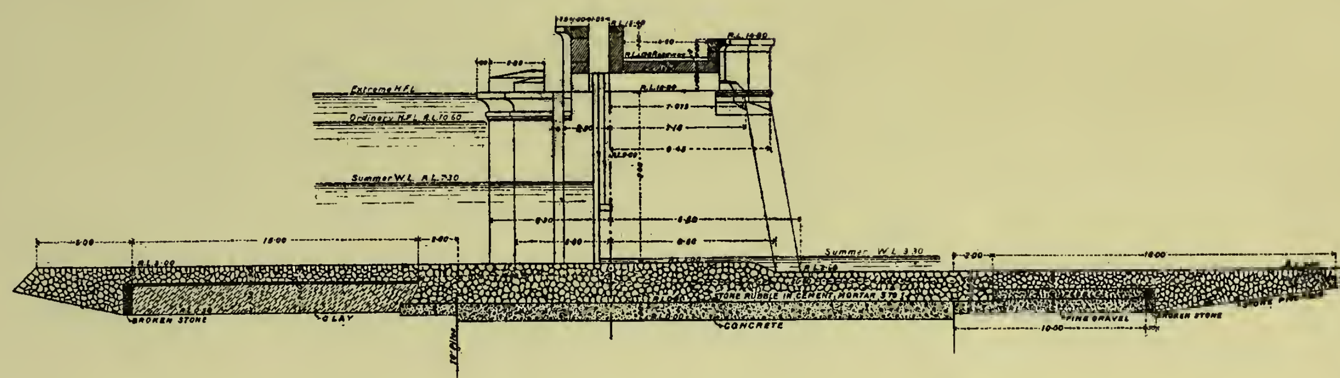
PLATE LXIV.

SECTION OF FLOOR AND SUPERSTRUCTURE

OF

ZIFTA BARRAGE

SCALE 1:400.



To face p. 664. Willcocks and Craig Egyptian Irrigation.

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built; and also a length of 71 metres of the regulator floor 3 metres thick, with the pier bases on this length up to 1·60 metres above floor level.

The actual expenditure for the year was £121,100, distributed as follows:—

Establishment	£3,076
Houses	6,638
Land	1,729
Sundries	537
Plant	497
Labour	20,739
Earthwork	7,518
Timber, coal, and stores	6,829
Ironwork	12,515
Purchase of materials	55,344
Transport	5,637
Total	£121,059

The remarkable part of this list of first season's expenditure is the small figure against plant. The purchase of plant was discouraged, because, in 1902, all the extensive plant of the Assiut Barrage, which is the property of Government, would be available. Fortunately, the Delta Barrage plant, which was used for the construction of the weirs, was available, and some of it was suitable for Zifta.

The quantities of permanent work done during the first season were:—

202 lineal metres of 16-feet piles driven,
116 ,, ,, of 10-feet ,, ,,
13,000 cubic metres of rubble and ashlar masonry,
5,328 ,, ,, of concrete,
5,410 ,, ,, of dry rubble work,

and a corresponding amount of filter bed and clay puddle.

Before the end of the year 1901 the second season's work was begun. The bottom grooves of these piers, which had been begun in the first season, were fixed, and the piers built up to the top of the grooves, 3 metres above floor level. The bays between these piers were thus made ready to pass the river discharge so as to allow of the rest of the foundation area being enclosed by earth dams and pumped out for the piles to be driven and the floor built. Over these piers a bridge for the passage of workmen has been since made: along the downstream dam the light railway runs, a temporary bridge being provided to carry this railway and to pass the river discharge. The work is progressing well and will, it is confidently expected, be in working order by the summer of 1903.

Mr F. A. Hurley, Director of Works, has been the resident engineer in charge, and has had to organise the whole work with very little assistance from headquarters.

The object of this work was explained in last year's report and a description given of the work itself. The portion of the foundations and superstructure constructed in 1901 served in the following season as a passage for the river discharge, and enabled the whole of the rest of the work to be taken in hand in one operation. The banks, enclosing the area of the foundations yet to be laid, were closed on 2nd January 1902. A bridge to carry the light railway across the waterway was made and the lines on both sides of the river were connected across it.

With commendable foresight Mr Hurley had had four pump-wells sunk the previous season ready to receive the pumps for the second season's work, so that there was a minimum of delay in getting the pumps to work. All four were at work by the 27th January. On 7th February the first cast-iron pile of the second season was driven; six pile-engines were at work by 16th February, and the whole of the piling was complete by 8th March, the total driven during these four weeks being 303 lineal metres of 16-feet piling and 411 metres of 10-feet piling. As the foundations of the east abutment proved to be to a great extent running sand, the piling was carried all round the back of it to connect the upstream and downstream lines of piling running the whole length of the barrage.

The operation of laying the concrete commenced on 24th February from the west end, and a week later from the east end. The concrete was made of five parts of broken stone, three of sand, and one of cement. The concrete was finished on 29th March, the cube executed being 8258 cubic metres.

There were but few springs met with, and those few were not formidable. The strongest springs were outside the work on the upstream side where they did not interfere with the work. A layer of clay below foundation level, overlying the sand, kept the springs from rising. It was only towards the east end of the barrage and under the abutment that the sand was reached. The floor throughout was a thoroughly sound piece of masonry without a defect, all springs having been skilfully dealt with and subdued.

While the concrete was being laid, the lock walls and piers of the previous season were being leisurely raised, and the rubble masonry layer over the concrete foundations was following the advance of the concrete. The floor was complete on 4th May, the total cube of rubble masonry in it being 17,424 cubic metres. The piers rose quickly upon the floor, and by the end of July were all up to the level of the springing of the arches (R.L. 12·00), and the lock and the east abutment were a metre more.

The clay aprons, filter bed, and up- and downstream pitching followed along as the floor was completed, and the following cubes were executed:—

	Cubic metres.
Clay apron	7,678
Filter bed	3,307
Pitching	25,068

On 31st July the containing banks were cut and the river discharge allowed to pass over the new season's work.

Most satisfactory progress was made throughout the season in consequence of the excellent arrangements made by Mr Hurley for the transport of materials, chiefly through the agency of the Light Railway Company. The manner in which this transport and the whole work was organised reflects great credit on the resident engineer and shows that he has great powers in this direction.

The masonry of the barrage and lock was continued during flood, the first arch having been started on 31st July. All the arches were turned by 20th September and the regulator gates slung into their grooves by 22nd October. By the end of 1902 the barrage was complete with the exception of the ashlar parapets, which were delayed by a failure in the ashlar supply. The total cube of brickwork executed was 25,817 cubic metres.

The following shows the quantities of work done in the two seasons :—

TABLE 236.—QUANTITIES OF WORK, ZIFTA BARRAGE.

		1901.	1902.	Total.
16-feet piling	lineal metres	202	303	535
10-feet piling	„	116	411	527
Concrete in cement . .	cubic metres	5,328	8,258	13,586
Rubble masonry in cement .	„	13,000	17,424	30,424
Dry rubble work . . .	„	5,410	25,068	30,478
Clay puddle	„	2,276	7,678	9,954
Filter bed	„	583	3,307	3,890
Brick masonry . . .	„	246	27,188	27,434
Ashlar masonry . . .	„	81	2,945	3,026
Ironwork	tons	16	1,044	1,060
Earthwork	cubic metres	262,933	519,688	782,621

The expenditure of the seasons under different heads is given below :—

TABLE 237.—EXPENDITURE, ZIFTA BARRAGE.

	1901.	1902.	Total.
	£	£	£
Establishment	3,076	4,098	7,174
Houses	6,638	1,598	8,236
Land	1,729	1,581	3,310
Sundries	527	824	1,361
Plant	497	6,071	6,568
Labour	20,739	37,261	58,000
Earthwork	7,518	14,946	22,464
Timber, coal and stores	6,829	25,691	32,520
Ironwork	12,515	16,725	29,240
Purchase of materials	55,344	19,812	75,156
Transport	5,637	15,984	21,621
Totals . . £	121,059	144,591	265,650

Considering that it was on 27th December 1900 that the grant for this barrage was first communicated, it is no mean feat to have practically completed this fine work by 27th December 1902. Mr Hurley had as his assistants, Mr L. N. Cooper, Mr W. W. Grant, and Mr R. A. Colvin."

A subsidiary weir has been constructed below the Zifta Barrage; we give an account of the work from the Irrigation Reports of 1905, 1906, and 1907, from the pen of Mr W. R. Williams, Inspector-General of Irrigation.

1905.—" During 1906 it is proposed to build a shutter weir below Zifta Barrage, to enable the very earliest supply of flood water passed down the Damietta branch to be directed into the canals above the barrage. The main object of the Zifta Barrage is to capture this early flood supply. During the past three seasons the weir has

been replaced by sand sadd, which it is of course impossible to maintain as long as required. The new weir will have its crest at the same level as the floor of the barrage, and will be provided with steel shutters 1½ metres high, which are to be worked hydraulically. The shutters will be kept erect till the flood is established, when a very moderate head on the barrage gives the upstream level required. When the shutters are down the weir will form no obstacle to navigation. There is no navigation in the Damietta branch till the flood is established. A good stock of materials were provided during the year, and the work is now in hand."

1906.—"As mentioned in last year's report, the collection of materials was commenced for the construction of a shutter weir to replace the annual sadd. The work was put in hand at the commencement of 1906, and all the masonry work of the weir was completed before the flood. The weir consists of a main wall of rubble masonry, grouted with cement, and a downstream wall made in the same way, the space between the two being filled with blocks of dry rubble.

On the top of the main core-wall are fitted steel drop-shutters, 1½ metres high, worked hydraulically, of which there are 108, in 12 bays. They were constructed by the well-known firm of Messrs Ransomes & Rapier, but unfortunately, being of a novel design, were not all delivered in time for their erection before the flood.

Two groups were erected, aggregating 54 metres in length, and were dropped, on the approach of the flood, by the agency of the hydraulic gear without the slightest difficulty. The remainder of the shutters will be erected during the coming summer. The works were ably supervised by Mr Stent.

The total expenditure was £28,183, made up as follows:—

	£
Labour, sundries, supply of materials, and petty works under £1000	9,707
Cement	5,510
Supply of ashlar, broken stone, talatat, and masonry work	6,424
Steel shutters	3,805
Dredging	1,619
Settlement of Mr Daujat in connection with Zifta Barrage subsidiary works	1,118
Total	£28,183"

1907.—"The balance from 1906 was £4816; of this only £4030 was used to complete the weir.

The total cost of the work from the commencement has been £32,213, or £787 less than the original estimate."

128. **The Esna Barrage** was designed by Sir Arthur Webb and built by Mr M. MacDonald. (See Plates LXV., LXVI., and LXVII.)

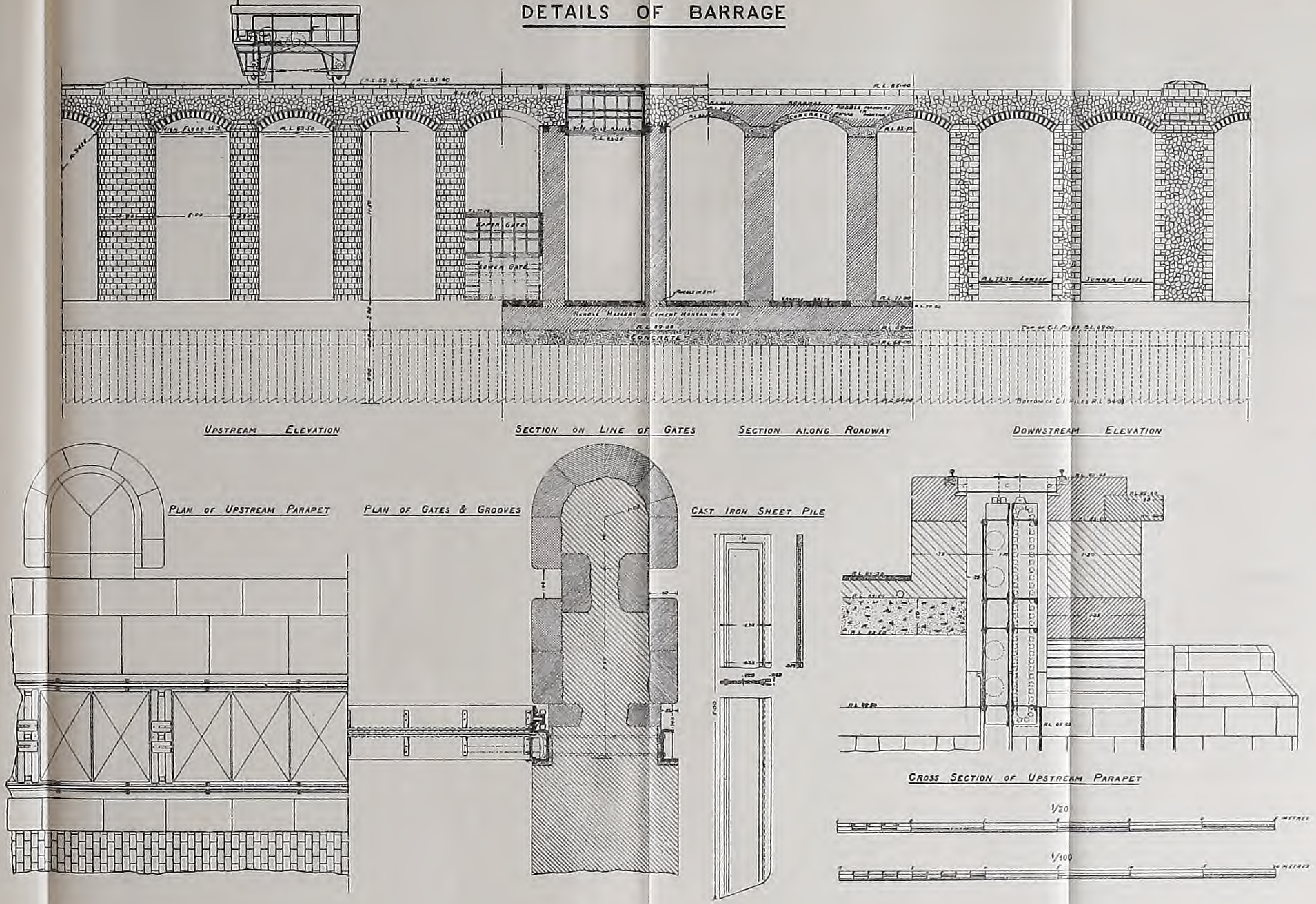
The following is from the pen of Sir William Garstin in the Report for 1906:—

"In order to improve the irrigation of the Kena Province during flood it was decided to construct a barrage across the Nile immediately north of Esna town.

The barrage will be an open weir of 120 bays, each 5 metres wide; abutment piers 4 metres thick occur at every tenth opening, the intermediate piers being 2 metres thick; the piers are spanned by arches carrying a roadway 6 metres wide.

ESNA BARRAGE

DETAILS OF BARRAGE



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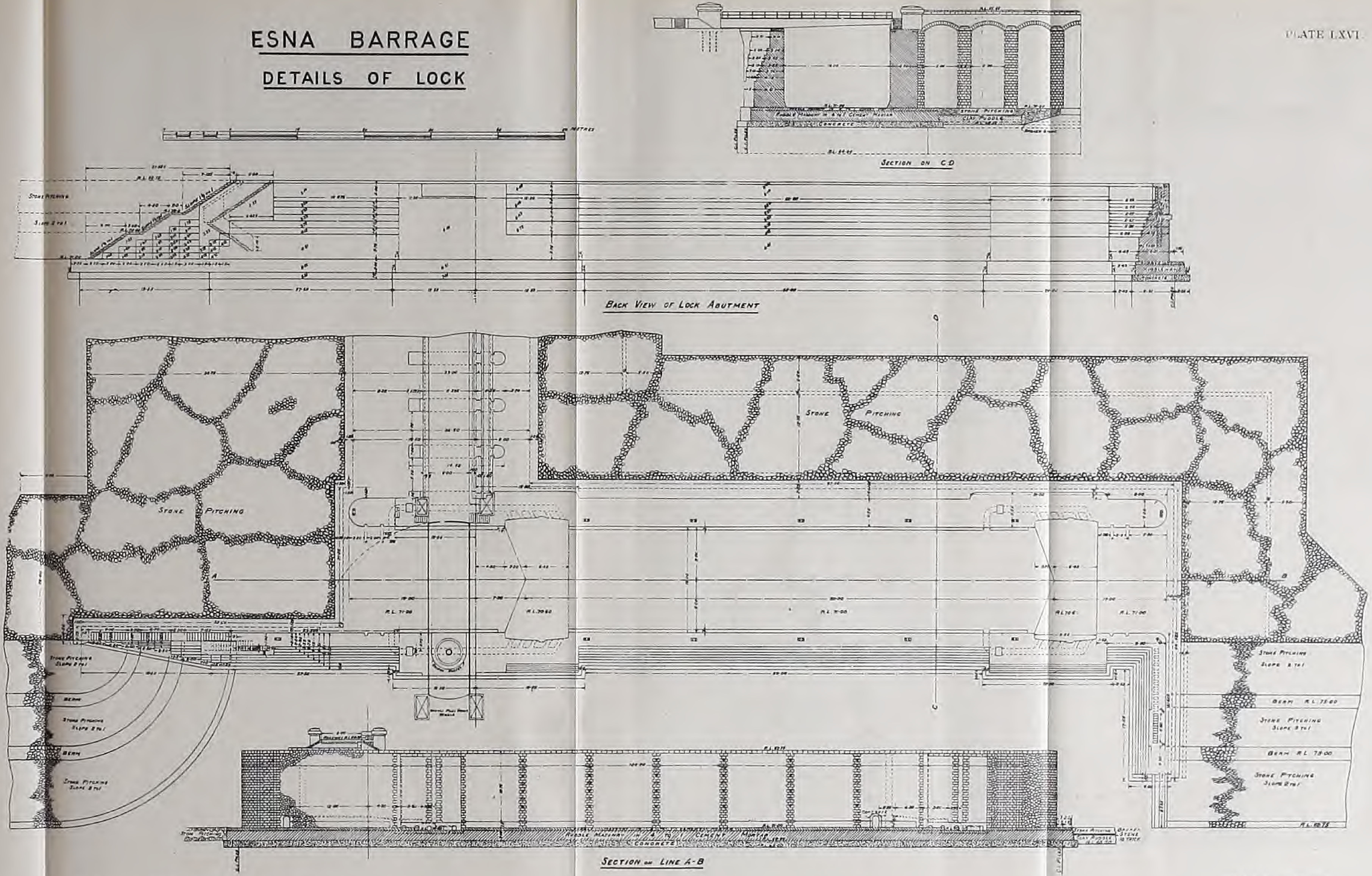
ESNA BARRAGE

DETAILS OF LOCK



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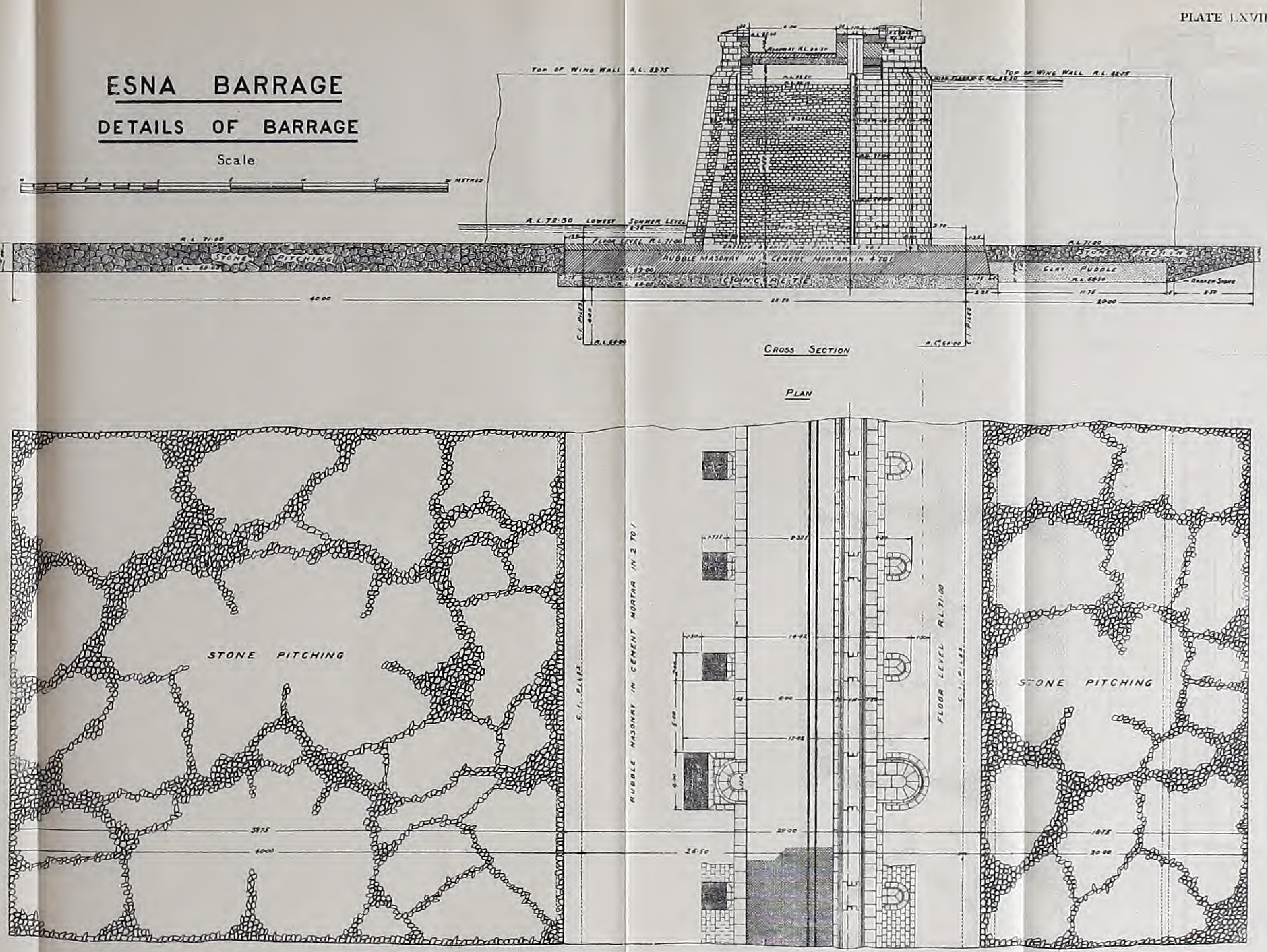
ESNA BARRAGE

DETAILS OF BARRAGE



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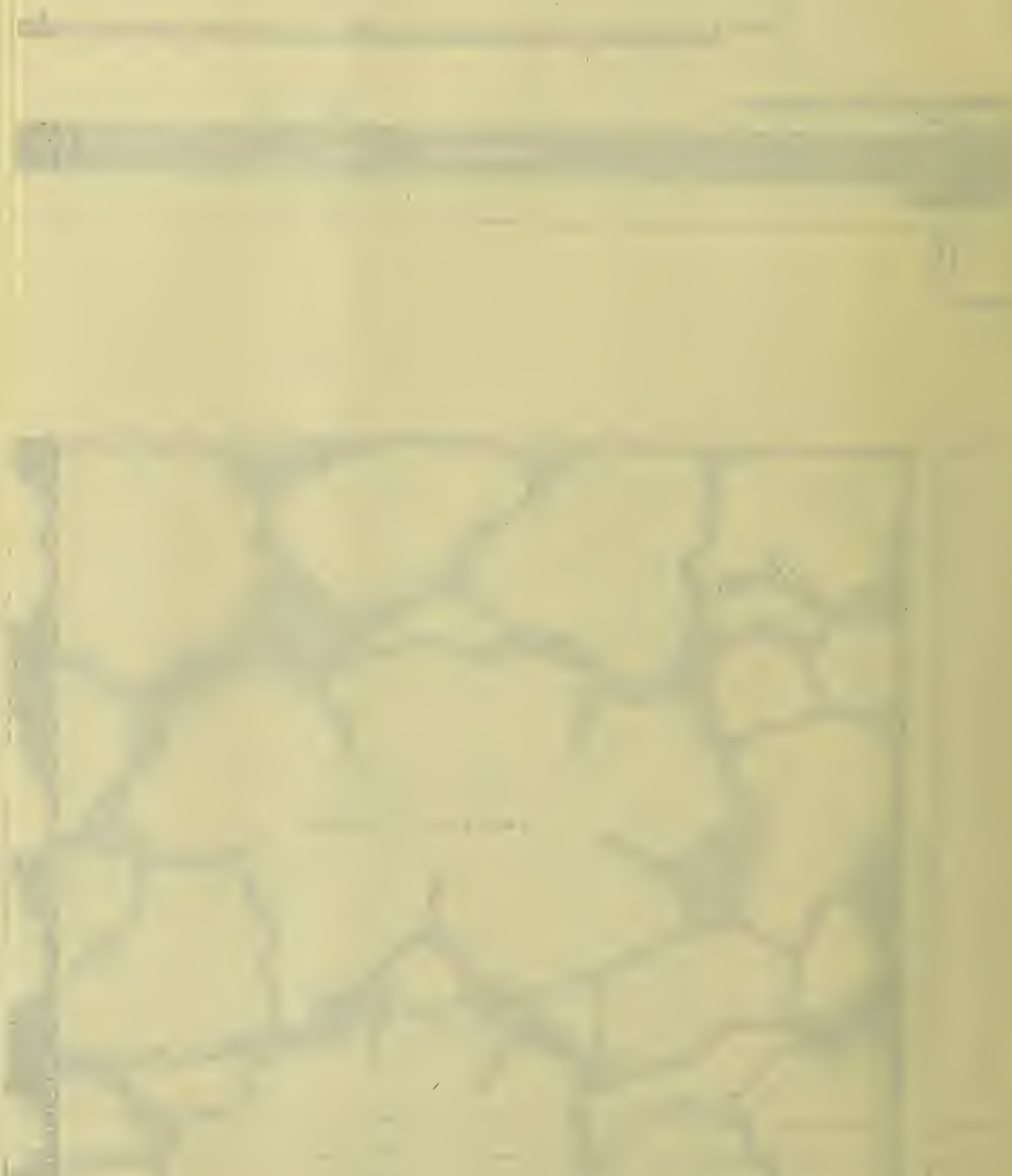
ESNA BARRAGE

DETAILS OF MASONRY



Two regulating gates, one upper and one lower, each 3 metres high, will be provided for each opening; double grooves will be so arranged as to allow both gates to drop on to the floor—thus the upper gate will act as a weir with a movable crest.

On the western side a lock 16 metres wide, large enough to pass the largest steamers on the Nile, will be provided.

The design is similar to that of the Assiut Barrage.

Early in the year a contract was made with Messrs John Aird & Co. for the construction of the works, except the steel- and ironwork, which was entrusted to Messrs Ransomes & Rapier."

The two following reports are from the pen of Mr M. MacDonald, Director-General of Reservoirs and Works, and appeared in the Irrigation Reports for 1907 and 1908:—

1907.—"The preparatory arrangements of building staff quarters and other preliminary works were commenced in April 1906, and continued throughout the summer and autumn under the supervision of Mr F. E. Wentworth Shields, resident engineer, assisted by Mr E. H. Lloyd — Mr John Blue conducting operations on behalf of Messrs John Aird & Company, the contractors.

A commencement was made with the permanent works in December 1906, when a programme of what might be undertaken during the ensuing year was laid down. This included the laying of about 400 metres out of the 860 metres in the floor of the barrage, and the partial building of 55 out of the 119 piers in the superstructure, as well as the practical completion of the masonry of the lock and the east abutment. This has been accomplished, and indeed in all classes of work the programme quantities have been exceeded, as 467 metres of floor have been laid down, and 63 piers partially built.

Aswan granite only, of a fine-grained and exceedingly durable quality, has been employed in the construction of the floor of the barrage, while for the superstructure, rubble and ashlar have been taken from the ancient quarries of Gebel Silsila.

The work on the west bank of the river included the erection of the navigation lock, as well as about 195 metres in length of the barrage proper.

The low-water channel of the river being close to the west bank, the construction of the sadds to enable the work to be laid in the dry was commenced early in December 1906.

In order to accelerate the work, the enclosed space was divided into two bays; the inner, or west bank one, being pumped dry on the 20th February 1907. Piling operations commenced on 27th February; the other classes of work followed as rapidly as possible in due succession, and continued until the programme works were completed at the end of July, together with an additional length of the floor and six additional piers. (See Plate LXVIII.)

The class of material met with in the foundation, and on which the work was erected, varies from a compact fine-grained sand under the barrage proper to a soft clay underneath the lock, being softest at the south-west corner where the clay appeared to be about 2 metres thick, through which a number of springs bubbled up from the underlying sand.

On the east bank the barrage foundation had to be excavated down to the required level through a wide sandy berm which lies uncovered by the Nile during the greater part of the year. Excavation in the dry was commenced in December

1906, continued until pumping became necessary about the 1st January 1907, and was completed about the 1st March, when the first permanent pile was driven. A commencement was made with laying the 1-metre thick bed of concrete between the pile heads about 28th March; the building of masonry in superstructure commenced about the 12th May. All these classes of work proceeded simultaneously until one after the other was finally completed before the arrival of the rising flood in August—the total length of floor laid being 275 metres.

The thirty-seven piers are graded temporarily downwards in height from the abutment outwards so that no great pressure may be laid on the unfinished end of the floor. The relative quantity of pitching was also placed in position, with the exception of the extensions on either side of the abutment, which were intended to be laid down during the following season.

The works have been erected on a compact bed of fine sand into which piles, especially at the abutment end, required a considerable amount of driving. Very few springs were encountered; the infiltration of water being a general ooze over the surface excavated, which rendered construction easy, and entitles the foundation to be described as an excellent one.

In order to facilitate sadding operations in the river during the 1907 and 1908 season, a canal has been cut in the dry through the sandy east bank berm leading into the centre of the completed floor, and having an opening downstream into the river. Arrangements were made for a bucket dredger and a sand-pump dredger to work in the channel during and after the flood. These have done good work in increasing the width and depth of this canal so as to allow it to carry as much as possible during the next low Nile season.

The groove castings have been set, as far as the height of masonry would allow, in the sixty-four sluice openings in hand. The groove and sill castings of the two lock gates have also been set.

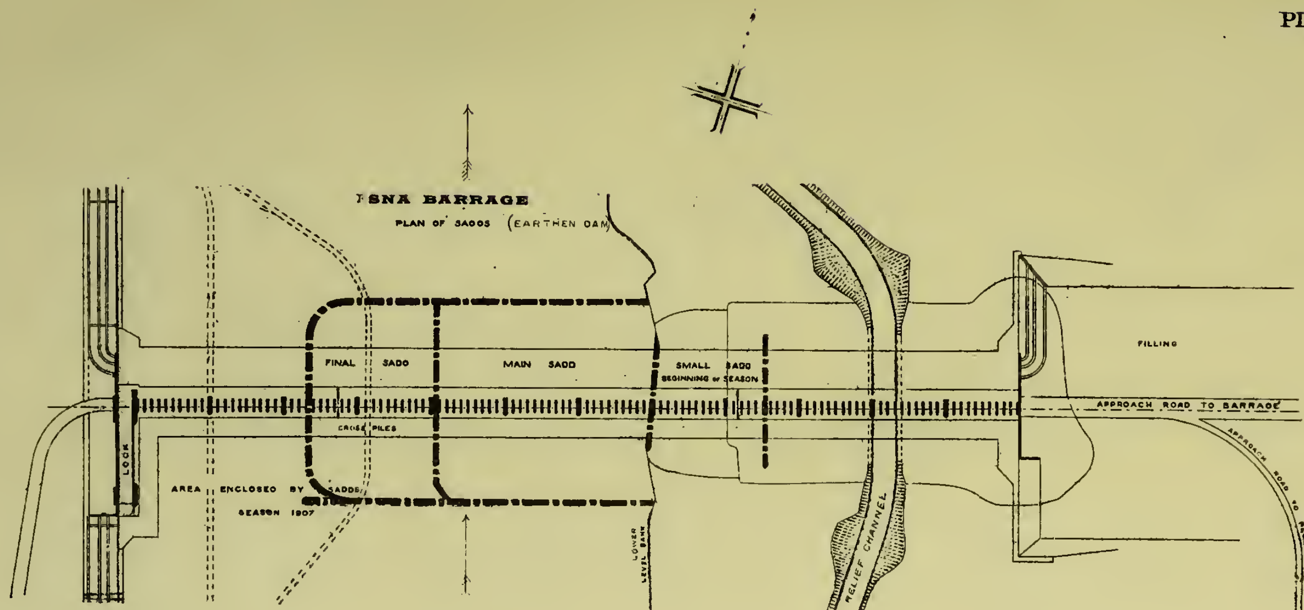
Mr Lloyd succeeded Mr Shields as resident engineer, who retired through ill-health.

Mr Blue, Messrs Airds' agent in charge of the works, had also to retire through ill-health at a critical stage in the operations. He was succeeded by Mr MacClure."

1908.—"As recorded in last year's Report, about 470 metres out of the 860 metres in the floor of the barrage, and the partial building of 63 out of the 119 piers in the superstructure, as well as the masonry in the lock and east abutment, had been completed.

The position then was that about a quarter of the length of the barrage had been constructed from each bank, leaving about one-half of the total length in the centre still to build. This was taken in hand in two main portions by the construction at the opening of the season, while the river was still fairly high, of a large inclosing sadd from the east bank: the river in the meantime passing through the finished and unfinished stretches to the west of this new sadd, as well as down the relief channel which was excavated in the preceding season through the sandy berm in the east bank. This large sadd was completed by the middle of January. Its construction caused some scour to take place in the bed of the river between it and the work on the west bank. To regulate this, a protective coating of 600 cubic metres of stone thrown in at the salient angle formed by the line of cross piles with the main piling proved sufficient to prevent undermining of the piles.

The greater part of this stone coating was removed after the final sadd was



NOTE: Season 1907 Sadds shewn in lines
" 1908 " " " "

Scale = $\frac{1}{7500}$

METRES 0 10 20 30 40 50 60 70 80 90 100 0 200 METRES

To face p. 670. Willcocks and Craig Egyptian Irrigation.

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pumped dry. A few stones sank deeply in the sand and could not be removed, causing rather more difficulty than was usually encountered in driving the piles, but the preliminary driving of a steel H-beam proved sufficient to clear the way, and allow them to be put in position.

Immediately after the construction of the first sadd, it was seen that the volume of the river * was likely to drop sufficiently to make it advisable to attempt the completion of the whole structure during the season; the only obstacle in the way being the necessity of employing a vastly greater proportion of bags to the cubic metre of sadd. This difficulty was removed by the Adviser agreeing to pay Messrs Aird & Co. for any additional cost they might have to expend over and above the cost under ordinary conditions. This final sadd took upwards of 800,000 bags, of which 700,000 were chargeable to the Government.

Before the sadd was finally closed the scoured portion of the river bed was made up with good sandy material thrown into the water from boats. After the sadd was pumped out it was found that very little levelling would have to be done on this material, as it was very equally deposited over the bed, and was as compact as any other portion of the foundation.

As in the preceding year's work few springs of any volume were encountered in the floor, although a large volume of water had to be contended with, which flowed under the south-western arm of the sack sadd at its junction with the completed portion of the building, where the lines of cross piling placed at right angles to the barrage proved effective in stopping any unmanageable leakage through or under the limestone pitching.

When laying the floor, with water oozing up at all points, the great difficulty was to prevent water carrying sand running from under the freshly laid concrete. For a portion of the work an effective variant (in addition to the usual scheme of laying a strip ahead of what had already been done, and filling in the gap afterwards) was adopted by putting small concrete cross walls with irregular surfaces about a half-metre in depth at intervals under the ordinary level of the floor.

The grouting pipes leading to the base of the structure, which were placed at intervals apart of a few metres in the floor, were finally grouted up, and in only two or three instances took any volume of grout: the maximum being about one metre cube.

One of the main alterations from the original design was in constructing the arches, concrete being substituted for burnt bricks, as it was found that the clay in the vicinity of Esna produced bricks of such inferior quality that it was inadvisable to use them in the barrage.

The works were commenced in April 1906, and completed at the end of December 1908, thus occupying a period of two years and eight months from the day the staff quarters were put in hand. Permanent work was commenced in December 1906. This remarkably rapid progress was undoubtedly due in a great measure to the exceptionally low summer discharge of 1908. The decision to take advantage of this ultimately rested with the Adviser of the Public Works Department.

Mr Lloyd was resident engineer, with Messrs Garrow and Gordon as assistants.

Messrs MacClure, Lamond, and Newman represented Messrs Aird & Co.; Mr Perry represented Messrs Ransomes & Rapier.

* The 1907 flood was an exceedingly low one and very favourable for the work.

Table 238.—Statement of Quantities, Rates, and Cost of Works, Esna Barrage.

Item.	Description in Schedule.	Quantities.	Rate.	Cost.
		Cubic metres.	£	£
1	Dry earthwork in excavation or filling .	953,495	·052	49,603
2	Dry earthwork in coffer-dams . .	399,038	·186	74,146
3	Wet excavation in foundations . .	573,639	·125	71,629
4	Pumping and unwatering . . .	...	...	70,364
		Tons.		
5	Cast-iron piling	3,933	13·50	53,096
		Cubic metres.		
6	Concrete in floor	31,632	2·20	69,599
7	Masonry in floor	59,706	2·12	126,697
8	Masonry in superstructure . . .	57,661	1·51	87,257
9	Ashlar masonry	11,438	4·43	50,706
10	Brickwork or concrete arches . .	3,591	3·00	10,806
11	Stone pitching	126,651	·36	45,091
12	Clay puddle	19,459	·24	4,670
		Square metres.		
13	Paving roadway	5,234	1·03	5,397
14	Sundry works and daywork accounts .	...	...	19,780
				738,841
15	Barrage gates, etc.	...	...	98,655
16	Dredging	...	...	11,047
17	Land	...	...	10,500
				859,043
	Additional Charges.			
18	Kilabia and Asfun regulators with gates	...	...	26,903
19	Administrative buildings and sanitary expenses	...	...	18,967
20	Salaries, etc., of staff to 31st December 1909	...	...	21,754
21	Plant purchased from Messrs Aird .	...	...	516
22	Materials for use to 31st December 1909, and workshop . . .	...	...	1,884
23	Sundry items and miscellaneous accounts	...	...	6,394
24	Amount allowed on Messrs Airds' outstanding claims by Adviser. .	...	...	1,705
25	Opening ceremony expenses . .	...	...	1,824
26	Allow for further possible works after 1909 flood and further supplementary works	...	...	6,010
				945,000

ABSTRACT OF QUANTITIES IN BARRAGE.

Dry earthwork in excavation	520,688 cubic metres
Filling	432,807 ,,
Coffer-dams	399,038 ,,
Wet earthwork in foundations	573,639 ,,
Total earthwork handled =	1,926,172 ,,
Days of 12-inch, 10-inch, and 8-inch pumps.	Working 4730 days
,, ,, ,,	Standing 667 ,,
Cast-iron piling	3,933 tons
Concrete in floor	31,632 cubic metres
Masonry in floor	59,706 ,,
Masonry in superstructure	57,661 ,,
Ashlar masonry	11,438 ,,
Concrete in arches	3,591 ,,
Total of building	164,028 ,,
Pitching	126,651 ,,
Clay puddle	19,459 ,,
Paving roadway	5,234 square metres"

One of the real difficulties encountered in building barrages across the existing beds of rivers is to secure a water-tight bank across the end of the preceding year's work. There is generally a good deal of pitching in the river both up- and downstream of the floor in order to protect the floor during the intervening flood. Light sheet-piling of the Lackawanna type could be very conveniently employed in this work. One or perhaps two rows of steel sheet-piling near each other, running parallel to the course of the river, continued through the pitching and some distance under the masonry of the floor along the alignment of part of the future bank, would ensure a water-tight joint. These sheet piles, parallel to the course of the river, might be left through the flood with their tops above the low water level of the river without causing any serious disturbance. So quickly is this sheet-piling driven and drawn that it might even be used, year after year, for important lengths of the "sadd" or bank.

In fig. 176 is given the section the pitching has finally taken at Esna. A mass of rubble at the end of the talus as proposed for the barrage on the Euphrates (Plate LXIII.) would have been a valuable asset to the Esna Barrage. Looking at fig. 176, it might even have been advantageous to grout the upper edge of the upstream pitching.

The following note on the working of the Esna Barrage has been kindly sent us by Mahomed Bey Shafîk, Inspector of the Fifth Circle of irrigation:—

"There are 120 bays in the barrage, each 5 metres wide. Each bay has two gates of 3 metres height each.

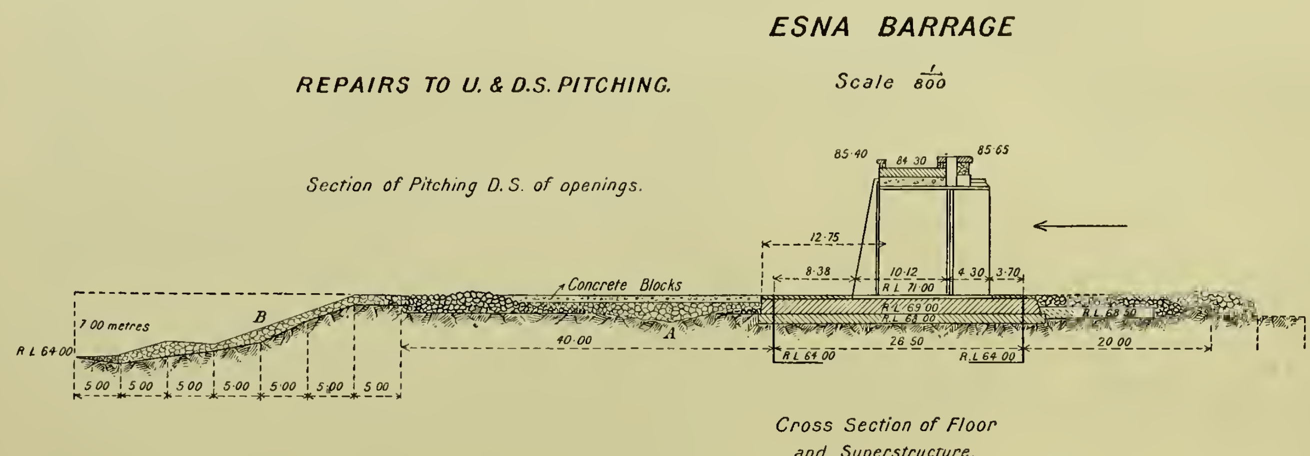


FIG. 176.

The pitching put in in 1910 on the up- and downstream sides of the barrage is drawn in fine lines ; and is to be found at the extreme upstream edge and at *A* and *B* on the downstream side.

It was noticed during the flood of 1910 that the backwater (while regulating on the barrage) raised the water of the river at the Ramadi Canal head situated 90 kilometres south of the barrage.

It appears that the fall of the water surface between Aswan and the Ramadi head (a distance of 90 kilometres) is:

6·18 metres when the barrage is closed.

6·44 metres when the barrage is opened.

0·26 metre effect of regulation.

This result is also confirmed by using Bresse's formula, which gives the following results:—

Table 239.—Backwater at the Esna Barrage.

Backwater, in metres.	Distance South of the Barrage, in kilometres.	Backwater, in metres.	Distance South of the Barrage, in kilometres.
1·40	0	0·70	37
1·30	4	0·60	44
1·20	8	0·50	52
1·10	13	0·40	63
1·00	18	0·30	76
0·90	24	0·20	95
0·80	30	0·10	126

Fig. 176 shows a section which may be taken as typical of the Esna Barrage during the summer of 1910.

4800 cubic metres of dry rubble have been tipped downstream of the barrage and 2500 on its upstream side, to bring the pitching to its original condition in the places where it is shown in fine lines.

A hole in the pitching of 24 × 25 metres was discovered downstream of bays No. 1 to 3 from the west just below the end of the floor. The depth varied from 0·50 to 2·50 metres, making a total of about 1000 cubic metres.

As directed by Mr Langley, Inspector-General of Irrigation, Upper Egypt, it was filled up with large stone to within 0·70 metre of the floor and then covered with a layer of cement concrete blocks.

The materials used to make one block of 1·50 metres × 1·00 metre × 0·70 metre (*i.e.* of 1 cubic metre) were thus:—

	Cubic metres.		£
Portland Cement	0·160	cost	0·830
Sand	0·310	,,	0·060
Broken stone and gravel . .	0·900	,,	0·180
Labour	...	,,	0·180
	1·370		1·250

Laying on floor by divers cost £0·750 per block.

It was proposed to cover the above stone with three layers of cement concrete in sacks, but in two experiments the bags filled with concrete were found not to adhere one to the other; and subsequently the proposal was definitely abandoned."

CHAPTER XII.

WATER STORAGE AND FLOOD PROTECTION.

129. **General.**—The first paragraph of the Report of 1894 on *Perennial Irrigation and Flood Protection for Egypt* by one of us was thus worded :—

"Of all the methods which Egypt has ever employed for the increase of her material wealth, there is only one which has never failed her. Whenever the country has turned to the Nile it has not been disappointed. It was so 4000 years ago when the problems of water storage and flood control engaged the attention of the Pharaohs of the Twelfth Dynasty. It is so to-day. All those dynasties in Egypt which have grappled with drought and inundation, the two great enemies of their country, have ensured the happiness of their people and deserved well to be remembered in history. When therefore at the beginning of this century Mohamed Ali merged the Egyptian question into the irrigation question, he followed in the steps of the very greatest of his predecessors and laid deep the foundations of his country's prosperity. Since his day Egypt has steadily persevered in the path laid out for her by his masterful hand, and to-day we are considering the question of extending, to the whole valley of the Nile, the perennial irrigation and consequent intense cultivation which he gave to part of the Delta, and of ensuring, for this future wealth, an immunity from the terrible evils of inundation."

This is the key-note of this chapter. We now quote from the Second edition of this work :—

"The most casual study of the preceding chapters will have made one acquainted with the fact that two systems of irrigation are practised side by side in Egypt. The ancient or basin system is confined to half of Upper Egypt, and the modern or perennial system is employed on the remaining half of Upper Egypt and the whole of Lower Egypt. The perennial system applied to suitable lands is more profitable than the basin system, but depends on the summer supply of the Nile, which is both limited and irregular in quantity. Basin irrigation depends on the flood, which is practically unlimited and very fairly regular in quantity. To reclaim waste lands, improve deteriorated lands, and renew old and fatigued lands, the basin system which has come down from the Pharaohs is the best. To develop good lands and

make them yield their maximum when skilfully handled, the perennial system has undoubtedly the advantage.

It would have been well for the country if, in all schemes for its development, the two systems had always gone hand in hand. Unfortunately for Egypt, in the first half of this century, when perennial irrigation was introduced, the relative advantages of the two systems were not understood, and every effort was made to convert basin irrigation into perennial, so as to increase the areas under cotton and sugar. No notice was taken of the fact that many of the tracts so treated were totally unfitted for perennial irrigation.

In Mohamed Ali's time, as has been already stated, the great preoccupation of the Government was the pressing on of the cultivation of cotton, and as this crop needed perennial irrigation, the securing of an abundant supply of water all the year round was the problem of the day.

The fame of the ancient Lake Mœris had made a profound impression on the mind of the viceroy, and he urged on his chief engineer, Linant Pasha,* the necessity of undertaking similar works. Linant Pasha first set himself to discover the site of the ancient lake, and then estimated roughly the cost of reconstructing it, but considered the cost prohibitive.† He also recommended Gebel Silsila as a suitable site for a weir and canal head.‡ The failure of the barrage discouraged the Government from undertaking new works, and the question dropped. In 1880 Count de la Motte,§ a Frenchman, took up the question of reservoirs and proposed a dam at Gebel Silsila and a reservoir to the south of it; the works were to have cost £4,000,000, exclusive of compensation, and the reservoir was to have contained 7,000,000,000 cubic metres of water. As a counter project to this, Mr Cope Whitehouse, ‖ an American gentleman, in 1882 suggested utilising the Wadi Rayan, a depression in the desert that had already been mentioned by Linant Pasha in his book ¶ and located by him on his hydrological map. Financial difficulties and the supposed failure of the barrage prevented the Egyptian Government at that time from considering the question of reservoirs for increasing the summer discharge of the Nile, as it had insufficient means of utilising the supply then existing. The subsequent success of the barrage gave new life to the question of reservoirs, and at the request of Sir Colin Scott-Moncrieff, the Government deputed Colonel Western, Director-General of Works, to give shape to the suggestions made by Mr Cope Whitehouse, to make plans of the Wadi Rayan and the deserts between it and the Nile, to find out the capacity of the reservoir and see if it could be utilised. Liernur Bey and a staff of engineers were placed under his direction, and they prepared the contoured map of the Wadi Rayan and surrounding deserts. Colonel Western's report, plans, and estimates were printed by Government.** Partly owing to financial considerations, but still more to the differences of opinion among the

* *Memoires sur les travaux publics en Egypte*, by Linant de Bellefonds, Paris, 1873, pp. 418 and 419.

† *Op. cit.*, pp. 88 and 420.

‡ *Op. cit.*, pp. 397 and 398.

§ *Le Nil*, by the Société d'études du Nil. Date on the plan of the Semne Cataract, by Mr Cotterill.

‖ *Bulletin of the American Geographical Society*, 1882, No. 2, pp. 22 and 24.

¶ *Memoirs sur les travaux publics en Egypte*, pp. 53 and 57.

** *Notes on the Wadi Rayan*, by Liernur Bey, Col. Western, and Sir Colin Scott-Moncrieff, Cairo, 1888.

officers of the Irrigation Department as to the feasibility of carrying out the project, the question was for the time shelved.

Meantime the other project of Count de la Motte for reservoirs in Nubia was being studied by me for the Egyptian Government, and, on its being unfavourably reported on, in 1889 Mr Prompt, a member of the Egyptian Railway Board, suggested utilising the trough of the Nile itself for a reservoir in the absence of the low plains which did not exist. As by this time the barrage repairs were practically completed, the Government, again at the request of Sir Colin Scott-Moncrieff, decided to study the question of the reservoirs anew, and Messrs Hewat, Roux, Clifton, Stent, Abder Rahman Rushdy, Abdalla Hassib, Mohamed Saber, and Mohamed Balig were attached to my staff.

Fortunately for the country, at the same time that the reservoir studies were undertaken, Colonel Ross was entrusted with the work of remodelling and improving the basins and basin canals south of Assiut, which had failed in the extremely low flood of 1888, owing to long neglect. He soon proved what was so earnestly insisted on in the first edition of this work, that basin irrigation had a great future before it just as perennial irrigation had. The one needed the skilful and plentiful use of flood water just as the other needed reservoirs. The first report was published in 1891, the next in 1894, and the last in 1895."

In the Report for 1894 it was assumed that provision should be made for the perennial irrigation of practically the whole of Upper Egypt, the cultivated area of Lower Egypt, and the better half of the waste lands of the Delta. It was moreover assumed that only one-third of the area would be under summer crops ; and, as the Albert Nile was badly sudded in those days, we could only count on a summer supply in the Nile in low years of 250 cubic metres per second. With these factors to guide one, it was calculated that 3,600,000.000 cubic metres of water should be stored in reservoirs to see the country through its summer irrigation.

130. **Water Storage, 1894.**—We quote from the Report of 1894 :—

"We have now to consider the methods of ensuring the required supply of water to Egypt. Water may be stored in reservoirs in the valley of the Nile, in depressions in the deserts outside of the Nile Valley, and in waste lands in the Delta.

Reservoirs in the Nile Valley can be formed by constructing, at places where a suitable rocky bed is available, solid submersible dams over whose crests the river in flood may discharge itself; or by constructing solid insubmersible dams and turning the Nile over waste weirs; or thirdly by building insubmersible dams provided with numerous under-sluices capable of discharging the flood waters without any material interference.

Of solid submersible dams there is a considerable number in existence, but they have been generally built on inconsiderable streams. The Turloch dam in California and the Betwa dam in India have, however, been constructed on considerable rivers. The Turloch dam is 102 metres long and has a maximum height of 40 metres, with a maximum depth of water over the crest of 4·5 metres.* The Betwa

* *Manual of Irrigation Engineering*, Wilson, New York, 1893, p. 295.

dam is 1080 metres long and has a maximum height of 18 metres, with a maximum depth of water over the crest of 5 metres.* At the Betwa dam the cross section is so designed that the water flowing over the dam in flood cannot strike the downstream face, while at Turloch the flood waters flow down the face of the dam.

Of solid insubmersible dams with waste weirs there are very many examples in existence. The earliest works of this kind are in Spain, while in France dams were first built on the modern scientific principle of width proportional to pressure. The whole question of dams of this type has been exhaustively treated by the Italian engineers Zoppi and Torricelli.† Such dams are built at times of considerable height: *e.g.*, the new Puentes dam in Spain is 72 metres above its base, while 50 metres is quite an ordinary height nowadays.

All solid dams are provided with small scouring sluices for the purpose of scouring out the mud which has deposited in the reservoirs owing to the ponding up of the rivers in flood. These sluices have, however, been a conspicuous failure on all muddy streams, except where the reservoir is very narrow and has its bed on a very steep slope. At the 1889 Paris International Congress for the utilisation of rivers, Mr Llaurado, a Spanish engineer, stated that in a few years the Puentes Reservoir had silted up to a vertical height of 14 metres, while the Nijar Reservoir had silted up to the very top of the dam.‡ Two reservoirs in Algeria have been conspicuous failures owing to the same cause.§ Indian irrigation literature teems with this subject. When we have to do with a river like the Nile, which has a slope of $\frac{1}{13,000}$, which occasionally runs liquid mud in August, and is heavily charged with matter in September and October, we may safely predict that any works which materially interfered with the flow of the water in flood, would immediately cause a heavy deposit of silt and steady obliteration of the reservoir. We may have an idea of the amount of silt the Nile is capable of depositing if we consider that, during an average flood at Aswan, the Nile carries in suspension

in August	. . . 11,440	kilograms per second
September	. . . 11,950	,, ,,
October	. . . 5,190	,, ,,
November	. . . 1,880	,, ,,

or, say, 85,000,000 tons of solid matter per annum, and nearly the whole of it in these four months.‖ The reservoir would be decreased by this amount per annum, while the soil of Egypt deprived of this rich mould would become poor indeed. These quantities are so serious that they exclude any hope of constructing solid dams of the ordinary type in the valley of the Nile downstream of Khartoum.

It now remains to consider the third class of reservoir dams, namely insubmersible dams with numerous under-sluices capable of discharging the flood waters without much more interference than the sill of an ordinary rapid on the

* *Public Works Department, N. W.P. India, Proceedings*, July 1888.

† *Laghi Artificiali dell' Algeria, della Francia e del Belgio*, Roma, 1886; *Laghi Artificiali e Irrigationi della Spagna*, Florence, 1888.

‡ *Congrès de l'utilisation des eaux fluviales*, Paris, 1889, pp. 7 and 8.

§ *Les Irrigations*, A. Ronna, Paris, 1888, vol. i. p. 521.

‖ Figures brought to date from paragraph 28.

Nile. With such dams the muddy flood waters will be able to pass on without parting with their silt, and when the comparatively clear winter supply has commenced to flow, the sluices in the dam will be gradually closed and the excess water in the river stored for use in summer. When I wrote my first report on dams on the 1st May 1891 * I thought that the idea was a novel one; since then, however, I have heard of the Bhatgarh Reservoir dam on the Nira River in Bombay, and have before me the report on the work.† On p. 16 of that report there is a quotation from a letter of Colonel Fife, written in 1889, in which he recommends that the dam be constructed with numerous under-sluices, so that floods with their silt might be passed through it and thus obviate the silt difficulty. Mr Whiting, the engineer in charge of the design, designed and built the dam with 15 sluices of 2·4 × 1·2 metres, spaced 5 metres apart. The sills of the sluices are from 5 to 11 metres above the foundation level of the dam, and 26 metres below highest flood level or high-water level of the reservoir, which is one and the same. For high floods there are two waste weirs with a joint waterway of 243 metres × 2·5 metres, with their sills 2·5 metres below high-flood level. The 15 under-sluices are regulated by means of cast-iron gates worked by screw gearing. After the first heavy floods in July, the river is discharged through the sluices with a head of from 1 metre to 4·5 metres, and occasionally there has been a head of 13 metres on the sills of the sluices. It is estimated that the maximum velocity through the under-sluices may rise to 18 metres per second, ‡ which seems very excessive. The whole design is extraordinarily bold and hardy. The section of the dam has not been increased at the under-sluices. The ashlar work is 38 centimetres thick."

131. **Proposed Aswan Reservoir,** 1894.—We continue the quotation from the Report of 1894:—

" For the Nile there has been proposed a waterway of 2000 square metres in the under-sluices and no waste weirs of any kind. The under-sluices will discharge the whole flood and ensure the reservoir from being obliterated. The mean maximum flood of the Nile at Aswan is 10,000 cubic metres per second, and this will be discharged with a mean velocity of 5 metres per second. The August flood of 8000 cubic metres per second will be discharged with a velocity of 4·25 metres approximately. An extraordinary flood of 14,000 cubic metres per second, which comes two or three times in twenty years and lasts a few days, will be discharged with a velocity of 7 metres per second. In the above calculations the velocities are taken at the section through the sills, while there is a drop of 50 centimetres in the floor immediately below the sills. The muddy flood discharge will be scarcely interfered with, and that is the principal point as far as the silting up of the reservoir is concerned. The granite ashlar under-sluices will be capable of standing the velocities which the water will attain.

After an inspection of the principal systems of regulation in Italy, France, England, India, and Egypt, I am of opinion that the only system of regulation capable of working on the scale and under the conditions imposed on us in the Nile

* *Nile Reservoirs*, Report by Sir Colin Scott-Moncrieff, Colonel Ross, and Mr Willcocks, Cairo, 1891.

† *Report of the Nira Canal Works*, Bombay, 1892, p. 18.

‡ *Op cit.*, p. 18.

Valley, are Stoney's patent self-balanced roller gates. I have seen these gates working in Ireland and England, and tested at Ipswich a pair of them for Holland. After a theoretical examination of the subject with Professor Benetti of the University of Bologna, and an exhaustive practical examination with Mr F. D. M. Stoney, M.Inst.C.E., we have concluded that gates 2 metres wide and 10 metres high will best meet our requirements. With such gates under 22 metres head of water, the working pressure upon the rollers can be easily maintained at one-third of a ton per lineal inch, which is Mr Stoney's safe limit. We shall also be able to dispense with arches and cover the sluices with granite lintels. All cut stone arches which are heavily loaded on the crown are liable to settlement, and leak when under a great head of water. A lintel is the safest and soundest covering when only ashlar is employed."

After an exhaustive review of the Report of 1894, Sir William Garstin recommended the Aswan Reservoir at R.L. 114·00 and referred the question to a technical commission composed of Sir Benjamin Baker, K.C.M.G., M. Boulé, and Signor Torricelli, from whose report we extract the following:—

"The Commission is in accord on the following important points:—

(*a*) That the valley of the Nile itself offers many advantages over the Wadi Rayan as a site of a storage reservoir.

(*b*) That the dam should not be solid, but have openings controlled by sluices of sufficient area to pass the heaviest floods.

(*c*) That there are no engineering difficulties in constructing such a dam in the Nile Valley and securing its permanent stability.

(*d*) That there are no sanitary objections to such a reservoir.

The Government proposes a dam provided with numerous and very large under-sluices which would pass the entire flood waters heavily charged as they would be with deposit. The Commission recognises the necessity of such a work in order that the muddy waters of the Nile flood might traverse the dam without parting with the matter held in suspension, as it is on this matter that the richness of Egypt in great part depends. The Commission is of opinion that any solid dam, which closed the Nile valley and raised very considerably the level of the Nile in flood, would result in a silting up of the reservoir and hurt severely the irrigation of Egypt. It is clearly proved in the report that the Nile in winter has abundance of water to spare for storage and subsequent use in summer, and the table given in Rogers Pasha's report shows how gradually and easily this can be done without any serious disturbance of the régime of the Nile.

The Commission is of opinion that a dam pierced by under-sluices could be constructed in the valley of the Nile, and that it would present no difficulty which the science of engineering could not master. The building materials at hand are good and reliable, and those to be imported from Europe could be easily and economically transported to the site of the work Such a work could be made so secure that its permanent stability would be assured, and it would be absolutely no source of danger to the country.

Rogers Pasha, the Director-General of the Sanitary Department, has published a report on the sanitary aspect of the proposed Nubian reservoirs, and the Commission

accepts completely the following conclusions enumerated in the note of Rogers Pasha dated March 1894:—

(*a*) The summer discharge of the Nile, downstream of the reservoir, will be augmented from the 5th May to the 25th July, and this will constitute a gain to the country from a sanitary point of view.

(*b*) The winter discharge of the river, during the filling of the reservoir, will be diminished, but not to an extent sufficiently great to prejudice the public health.

(*c*) The quality of the water in the Nile and in the reservoir will gradually deteriorate as the summer advances, but this deterioration will be less than that which takes place now that there is no reservoir.

(*d*) Special precautions should be taken to prevent the pollution of the reservoir, and the Commission points to the removal of the cemeteries as one of the precautions which should be adopted (mentioned in paragraph 24 of Rogers Pasha's note).

The majority of the Commission, composed of Sir Benjamin Baker and Signor Torricelli, is of opinion that the studies of the Nile Valley and of the reservoir question in general by the large staff of Government engineers employed on this work during the past four years, coupled with the personal inspection of the river up to Wadi Halfa made by the Commission itself, renders it possible for them to make at once a selection from the different projects submitted for their consideration.

As regards the design and construction of any dam across the Nile Valley, the majority of the Commission is of opinion that the absolute security of the work must be the first consideration. The conditions to ensure this are:—

(1) A solid rock foundation to support the masonry and to resist the action of the water.

(2) A considerable length of dam, so that the openings may not be close together, that the stability of the work may approach as nearly as possible to that of a solid dam, and that at the same time the action of the water may not be concentrated but be distributed over a great width of the river bed.

(3) Shallow water, so that the total height of the dam above the foundation may be as small as possible.

The majority of the Commission considers that there is no site in the Nile Valley between Cairo and Wadi Halfa complying with the preceding conditions, except the site indicated by the Government engineers at the head of the first cataract downstream of Philæ Island, and it unhesitatingly recommends the adoption of that site.

Two other sites have been taken into consideration by the Government. They are *Silsila and Kalabsha.*

The majority of the Commission considers the Nubian sandstone at *Silsila*, with its strata of clay, which could be dissolved and removed under a great head of water, as unfit for a dam over 10 metres in height. For an open dam, such as those proposed for the Nile, they reject the Nubian sandstone as absolutely unsafe.

As regards *Kalabsha*, it is of opinion that although the rock is all that could be desired, the great depth of the water and the narrowness of the river render the construction of a dam practically impossible on account of its immense cost. During the working season the depth of water would be over 22 metres, and coffer-

dams as proposed by the Government would be an impossibility. The foundations would have to be put in by compressed air, and as the dam would have a final height of 49 metres and be subjected to water pressure, the class of work would be enormously expensive. In addition to this, it would be necessary to execute extensive tunnels and cuttings through the granite hills to provide the waterway, and this again would be costly.

As regards the general design of the dam, the majority of the Commission approves of a single dam as proposed by Government. It is of opinion that the only means of storing, in Egyptian territory, the large quantity of water needed for the perennial irrigation of Egypt is the construction of a high-level reservoir.

While the majority of the Commission accepts in principle the Government project of a single dam, it proposes the following rules and modifications of some of the Government proposals, in order to ensure the absolute stability of the work :—

(1) The maximum height of the open dam to be 35 metres and never greater. This is also the maximum adopted by the Government engineers.

(2) The maximum head of water to be 25 metres as proposed by Government.

(3) The widths of the openings to be 2 metres as proposed by Government, but the widths of piers to be 5 metres instead of 3 metres.

(5) The maximum pressure on each pier of 7 metres must be everywhere 5 kilograms per square centimetre, and there must be no tension anywhere. The calculation of each pier must be made independently of the support received from the dam between the piers when the calculations for the 'full reservoir' are being made. For the 'empty reservoir' calculations the dam between the piers will be considered. The water level must be taken as 3 metres above the maximum full water level of the reservoir, to allow for waves and accidental rising of the water surface.

(6) Each 2-metre wide opening is to consist of 2 sluices. Each sluice to be 3·75 metres high with one immediately above the other. The area of waterway of the two sluices, or of one opening, to be exactly 14 square metres.

(7) Each opening to be regulated by a sluice gate 8 metres × 2 metres.

(8) In the Government designs the sluices are lined with granite ashlar, but the majority of the Commission is of opinion that cast iron, 35 millimetres in thickness, would be far preferable. The employment of cast iron would not necessitate the importation of much skilled labour from abroad; it would permit of a far more perfect joint between the sluice and the regulating apparatus; and its use would reduce the time needed to build the dam.

Cast-iron linings would not be more expensive than granite ashlar, while the time needed to dress and build the granite ashlar would be three times that needed to cast and put up the pipes.

The length of the dam at Aswan proposed by the majority of the Commission is exactly the same as that proposed by the Government. The modifications introduced by the former result in a better distribution of the openings, with wider piers, and a greater power of scattering the water as it issues from the under-sluices. The length of the dam will be unaltered, and the cost in consequence will not be increased. The increase of cost, owing to the modifications of the Commission, has nothing to do with the length of the dam : it is owing to the fact that the maximum

pressure has been lowered from 6·5 kilograms per square centimetre to 5 kilograms per square centimetre, and the water surface for purposes of calculation has been raised 3 metres.

The majority of the Commission thinks that the velocities of 4 metres per second in mean maximum floods, and of 7 metres per second in times of extraordinary flood, are absolutely safe for cast-iron pipes. In existing dams, notably at Nira, velocities are much higher than those quoted, and they traverse sluices lined, not with cast iron, but with granite. The objection to a single dam on this head is groundless.

The majority of the Commission thinks that a head of water of 1·75 metres in August, when the Nile is heavily charged with deposit, of 2 metres during the interval of a mean maximum flood, and of 4 metres during extraordinary floods, which come only two or three times for a few days during a period of twenty years, will not cause a silting up of the reservoir sufficiently serious to modify the capacity of the reservoir or hurt the agriculture of Egypt by depriving the water of deposit. The bed of the Nile will be slightly raised, but as the water in the reservoir will not be utilised below a level 4 metres above the present minimum summer, the small amount of mud deposit will in no way affect the capacity of the reservoir.

The Government has before it a good project, worthy of all confidence, a project which even the member of the Commission differing from the majority considers 'realisable,' although he 'cannot associate himself with any propositions for inundating or even modifying in any manner whatsoever the relics of the temples and other buildings raised in ancient times on the island of Philæ, because, in doing so, he would be certain to be despised, not only by his own countrymen, but by the public opinion of the whole of Europe.'

Neglecting the question of Philæ, a question on which the Government has not asked the Commission for an opinion, the majority of the Commission recommends a single dam pierced by numerous sluices lined with cast iron, as the best and safest solution of the question of reservoirs. It accepts also the Aswan cataract as the best site. It persists in its belief that there is no necessity for it to advise the Government to make further studies in order to discover better projects or better sites, for it is convinced they do not exist."

Reviewing the Report of the Technical Commission, Sir William Garstin, G.C.M.G., Under Secretary of Public Works, wrote as follows :—

"The majority of the Commission concludes by saying that it recommends a single dam pierced with numerous under-sluices as the best and safest solution of the reservoir problem. It accepts the Aswan cataract as the best, and indeed as the only practicable site for the construction of such a dam.

Sir Benjamin Baker and Signor Torricelli have discussed so ably and thoroughly all the questions submitted to the Commission, that I have practically nothing left to add. I can only endorse every word they say with respect to the single dam at Aswan, which project was that submitted by Mr Willcocks and approved of by me. I can only express my great satisfaction that our proposals have been approved by men so eminent in their profession as the two gentlemen above named.

I come lastly to that portion of the subject which with a large number of

persons is doubtless the most important, as it certainly is the most difficult, question of all those to be solved. I may say at once that after reading Messrs Baker and Torricelli's report I completely share their opinion that the Aswan cataract site is the only possible one for a reservoir dam, and further that a single dam of sufficient height to store water for the wants of Egypt is the only possible solution of the reservoir problem as far as that portion of the Nile Valley that lies between Cairo and Wadi Halfa is concerned. The Government of Egypt must then decide either to construct a single dam at Aswan or to postpone the question altogether until that portion of the river lying to the south of the present Egyptian frontier has been thoroughly explored and studied. If its decision be in favour of the former solution, it must also decide as to what is to become of the Philæ Temple. As regards this part of the question, I have little to add to the opinion I expressed on the subject in my previous note. When I wrote my first report I thought and hoped that possible alternative sites existed, but the report of Messrs Baker and Torricelli clearly shows that such is not the case, and that the dam, if made, can only be made at Aswan. This narrows the question to very small limits, and leaves the Egyptian Government face to face with the problem as to what is to be done with Philæ. If the dam be made at Aswan, the temple must either be raised, removed, or submerged. I have already suggested its removal to the island of Biga, and Sir Benjamin Baker suggests raising it to such a height as to place it above the level of the highest flood water. Mr Somers Clarke, the well-known archæologist, has suggested a third alternative. This is, that if it be decided to leave the temple where it is—which in the case of the dam being made would result in its annual submersion,—a complete archæological survey and investigation be made of Nubia, and that accurate drawings and surveys should be made of all such relics of interest as would be submerged by the reservoir: that such of these monuments as would bear transporting should be transported to the Cairo Museum, so that if the submersion of these remains be decided upon as unavoidable, as much should be done as lay in our power to record them and preserve their interesting features from obliteration. Should this proposal be carried out, I would suggest that Monsieur de Morgan be asked to undertake the work, and that a sum of say £50,000 be added to the dam estimate to cover the expenditure required.

It is of course for the Egyptian Government to decide upon this point, and to it I leave the question. It must duly weigh the sentiment connected with the temple and its surroundings, against the benefits to be derived by the country in general from the construction of the reservoir. I trust, however, that we, its advisers, who are so unfortunately thrust into the position of having to recommend a work that will involve possible damage to one of the most beautiful monuments in the world will, if not now, be some day acquitted of having done this wantonly and without regret."

The Egyptian Government, pressed hard by archæologists, finally decided to lower the water surface of the reservoir from R.L. 114 to R.L. 106 metres, and to make an effort to save Philæ Temple. This action of the archæologists has hurt the reservoir and will not in the end save the temple. If either our proposal to remove the temple to the adjoining island of Biga, or Sir Benjamin Baker's proposal to raise it vertically upwards on its own base had been adopted, Egypt might have had a reservoir two and a half

times as capacious as the one under construction, and moreover the temple would have been preserved for all time.

During the execution of the Tiber improvement works at Rome, Italian engineers dismantled and put together stone by stone, exactly as it was before, an important masonry bridge of large span which dated from the time of the Republic, and was an object of the most cherished regard. They were preparing to treat the St Angelo bridge in the same way. The "Biga" island was admirably suited for the site of a temple, and well above the high-water level of the largest reservoir.

The following selections are from the final Report of 1895 :—

"*The original project for a Reservoir for Egypt*, described in *Perennial Irrigation and Flood Protection for Egypt*,* was submitted to a technical Commission, whose report was printed by the Egyptian Government.† The Commission proposed certain modifications which affected the stability of the dam; certain other modifications which affect the size of the reservoir have also been introduced to meet the views of archæologists and men of science. The final designs and specification which accompany this report have been drawn up in accordance with the decision of Sir William Garstin, K.C.M.G., and in consultation with Sir Benjamin Baker, K.C.M.G., F.R.S., who has been appointed consulting engineer to the works by the Egyptian Government. In my original report I had recommended a reservoir at the first cataract, with its water surface at R.L 118·00 metres, storing 3,700,000,000 cubic metres of water. In case the first cataract were not adopted for the reservoir dam, I recommended the construction of regulating works at the rocky outlets of Lakes Albert and Victoria (especially the former). Since then we have further considered the problem, and have concluded that whether the sources of the Nile or the sills of any of the other cataracts of the Nile are utilised for water storage, it is absolutely necessary, in the interests of irrigation, to have near at hand, at the point where the Nile enters Egypt, a reserve of water to meet any contingencies which might arise. These contingencies would arise from the fact that some of the more important summer crops are incapable of standing a ten days' drought, while the summer discharges of the reservoirs would probably take eleven days to reach the canal heads from the first cataract, twenty days from the second, twenty-three days from the third, thirty-three from the fifth, thirty-nine from the sixth, and ninety days from Lake Victoria.

2. The *reservoir dam* will be constructed across the head of the Aswan cataract. This is the only site where a work of the nature of a dam can be constructed with perfect safety in the Nile Valley north of Wadi Halfa. The maximum upstream water level will be R.L. 106·00 metres, and the minimum level on the downstream side will be R.L. 86·00 metres. The greatest head of water will be 20 metres.

The storage capacity of the reservoir will be 1,065,000,000 cubic metres. The reservoir will be filled between November and April, after the floods have passed, and will be discharged during May, June, and July.

4. The proposed work is *an insubmersible masonry dam* pierced by 140 under-

* *Perennial Irrigation and Flood Protection for Egypt*, Cairo, 1894.

† *Report of the Technical Commission on Reservoirs*, Cairo, 1894.

sluices of 14 square metres area each, and by 40 upper sluices of 7 square metres area each. The total area of opening will be 1960 square metres for the under-sluices and 280 square metres for the upper sluices, or 2240 square metres in all. The dam will have a total length of 1950 metres on one perfectly straight line, and will be founded everywhere on the soundest granite rock of the cataract. The maximum head of water will be 20 metres, and the maximum height of water will be 28 metres. The width of the dam at top will be 7 metres, and at bottom 24·50 metres. The calculations have been made in accordance with the recommendation of the Technical Commission, which recommendation was to the effect that the maximum theoretical pressure on the downstream toe of the dam when subjected to its maximum strain was not to exceed 5 kilograms per square centimetre; that the openings were not to be greater than 2 metres in width; and that the piers were not to be less than 5 metres in width. The 140 under-sluices will be lined with granite ashlar, and the 40 upper sluices with cast iron. The sluices will be 2 metres wide and 7 metres high, worked by Stoney's patent gates. Ordinarily, the sluices will be 7 metres apart centre to centre. Every tenth sluice and its neighbour will, however, be 12 metres apart centre to centre. The navigation will be effected by means of a canal provided with locks and traversing the extreme left flank of the dam. During the whole of the flood all the sluices will be fully open, and the flood waters of the Nile will be discharged through them. The maximum discharge of an extraordinary flood is 14,000 cubic metres per second, and this will traverse the sluices of the dam with a velocity of 6·25 metres per second. The mean maximum flood of the Nile at Aswan is 10,000 cubic metres per second, and this will be discharged with a velocity of 4·75 metres per second.

The muddy August flood of 8000 cubic metres per second will be discharged with a velocity of 4 metres per second.

The *navigation channel*, with a total length of 1600 metres, will be on the left bank, and will be partially excavated out of the living rock and partially banked. The intake will be well removed from the draw-off water on the upstream side of the dam, while the outlet will be similarly removed from the wash on the down-stream side. The bed width will be 15 metres. When the channel is in cutting, it will be provided with continuous floating balks of pine on either side, in order to protect boats and steamers from the rough surface of the blasted granite.

The Locks.—The total drop of 21 metres will be divided into three drops of 6 metres each and one of 3 metres. The locks will have a clear length of 75 metres each and a width of 9·50 metres. The lock gates will range in height between 19 metres and 9 metres. The excessive height of the upper lock gates is rendered necessary by the fact that navigation has to be kept open when the reservoir is full as well as when it is empty. Considering the height of the gates, it has been considered advisable to adopt the plan recommended for the Nicaragua Canal, and to have single-leaved gates rolling back into recesses at right angles to the direction of the lock. Mr F. G. M. Stoney, M.Inst.C.E., who designed the sluice gates, has designed the lock gates to meet all the requirements. His special report on the gates is contained in the specification. A lift bridge, hinged on to and in continuation of a fixed bridge over the recess, carries a pair of rails. On this railway travels a carriage supported by numerous rollers. From the carriage is suspended the lock gate. When the lock is open, the lift part of the bridge stands vertical and the gate is suspended within the recess. When the lock has to be closed, the lift bridge

is lowered and spans the lock, the carriage carrying the gate is rolled across the lock, and the lock gate rests against the steel quoins at the sides and the steel sill at the bottom. The great depths which will exist at all times when the different gates are being worked, will lend themselves to the filling and emptying of the locks by means of valve openings in the gates themselves. As a matter of extreme precaution, every single gate has been designed of sufficient strength to stand a head of water equal to its own height. The lock walls will have a batter of 1 in 25, and in width are equal to half their height. Indeed, in every calculation every contingency has been allowed for, and extreme factors of safety have been uniformly adopted. It must, moreover, be borne in mind, that where the lock gates are 19 metres high, the maximum head of water in actual practice will be only 3 metres; while the top 12 metres alone of the height of the wall will be of masonry, since the bottom 7 metres will be blasted out of the solid granite rock."

The estimate of the cost of the work is as follows:—

Dam.

	Cubic metres.			
Excavation	62,000	at	£·20	= £12,400
Rubble masonry	300,000	at	1·00	= 300,000
Granite ashlar	26,000	at	7·00	= 182,000
Sandstone ashlar	24,000	at	3·00	= 72,000
Brickwork	5,000	at	1·50	= 7,500
	Square metres.			
Regulating apparatus	2400	at	£75	= 180,000
Coffer dams and pumping				= 80,000
Total				£834,000

Lock.

	Cubic metres.			
Excavation	125,000	at	£·20	= £25,000
Rubble masonry	21,000	at	1·00	= 21,000
Brickwork	21,000	at	2·00	= 42,000
Granite ashlar	1,000	at	7·00	= 7,000
Sandstone ashlar	1,000	at	3·00	= 3,000
	Square metres.			
Lock gates	600	at	£75	= 45,000
Total				£143,000

Dam	£834,000
Lock	143,000
Total	£977,000
Contingencies at 10 per cent. and land compensation	248,000
Grand total	£1,225,000

Cost of water stored per 1000 cubic metres $= \frac{1,225,000 \times 1000}{1,065,000,000} =$ £1·20.

The water capable of utilisation will only be three-quarters of this quantity, but as the reservoir level can be raised 1 metre to R L. 107·00, we may consider 1,015,000,000 as the quantity capable of utilisation.

It will have been noticed that the under-sluices as originally designed were to have been lined with ashlar; subsequently the Technical Commission proposed cast iron, but the final design was made with granite.

As one hears it occasionally affirmed that the Aswan dam deprives the Nile flood of its valuable sediment, we quote from the preface by Sir William Garstin to the *Album of the Nile Reservoir Works*:—

"It has already been explained that the definite study of the projects was first commenced in 1890. In that year Mr Willcocks, of the Irrigation Service, was directed to survey the Nile Valley, as far south as the second cataract, and to report upon the best method of attaining the required end. His proposals, including the necessary plans and estimates, were presented to the Government early in the year 1894.

To him must be assigned the honour of having designed the great work just completed at Aswan. His project differed from all prior schemes in one most important point. He quickly saw that any construction in the river bed, tending to check the velocity of the current, at the time that the water was most heavily charged with sediment, would inevitably cause a very considerable deposit of silt in the reach of river upstream of the obstacle. Successive floods would still further add to this deposit and thus raise the river bed; so that in a few years' time the storage capacity of any reservoir thus constructed would be very largely diminished. To obviate this possibility, he designed a dam of great height and section, pierced with a sufficient number of openings to permit of the river, when in flood, passing through it with a comparatively uninterrupted velocity and discharge.

Briefly stated, his principle was: To allow the silt-laden water to pass through the dam unchecked, and not to commence storage until such time as the water should be clear and free from sediment. There is no doubt that this principle was sound for a river like the Nile, and the advisers of the Egyptian Government accepted it as such."

132. **Proposed Wadi Rayan Reservoir, 1894.**—At the same time that the project for the Aswan dam was prepared, a project for the Wadi Rayan Reservoir was also taken in hand. Both were published together in the 1894 Report, from which we now quote:—

"After a careful examination of the deserts on both banks of the river between Wadi Halfa and Cairo, no depression has been found in the deserts outside the Nile Valley capable of being utilised as a Reservoir except the Wadi Rayan.

The Wadi Rayan Reservoir.—Plate XXXIII. gives the plan of the Wadi Rayan, the deserts between it and the Nile Valley, and the cultivated land. The plan was begun by Colonel Western, and has been completed by me. The Wadi Rayan is a depression to the S.W. of the province of Fayum. Its lowest point is 42 metres below sea-level. It is separated from the Fayum by a limestone ridge which is generally from 34 to 60 metres above sea-level, except at two places where it falls

to 26 metres above sea-level on a length of 600 metres. At R.L. 27 the Wadi and adjoining depressions have an area of 673 square kilometres and contain 18,743,000,000 cubic metres. Between them and the Nile Valley lie 30 kilometres of desert, of which 11 kilometres are occupied by a marked depression discovered by Liernur Bey in 1887. At the extreme western edge of the Nile Valley, which is here some 20 kilometres wide, flows the Bahr Yusuf, and at the extreme eastern edge is the Nile. I propose to put the Nile in communication with the Wadi Rayan by means of an inlet and outlet canal combined, for both filling the reservoir and discharging its waters.

Along the line of the canal there are alternating strata of sandy clay and clay to a depth of 10 metres. Near this line lie the ruins of Ahnessa (Herakliopolis) the ancient capital of the island Nome of Egypt. The island has to-day disappeared, but the sandy character of the strata bears witness to the increased velocity given here to the Nile flood by the draw of Lake Mœris. The gradual disappearance of the lake was accompanied by the gradual silting up of the western channel of the Nile. The soil along the outlet canal is inferior to that ordinarily met with in Egypt, and the spring level is in places near the surface. As this canal will run with a severe velocity, allowance has been made in the estimates for pitching its bed and slopes. On leaving the Nile Valley and entering the deserts, we meet with sand at the surface, or sand conglomerate with gypsum and salt, and then a yellow marl with Epsom salts, and finally a bitter plastic clay of a black colour overlying the Parisian limestone. The clays and marls are most extensive in the narrow neck of land between the Nile Valley and the Fayum, and for a distance of some 10 kilometres south of it. They rise to a height of 70 metres above sea-level. There are none of these marls inside the Wadi Rayan or in the depressions connected with it; but as they have to be traversed by the canals, they constitute a very serious factor in the question of the Wadi Rayan Reservoir. They are extraordinarily easily dissolved in water, and it is on their account that the alignment of the inlet canal has been chosen along the Bahr Bilama, where we have only 2500 metres of them, instead of along the alternative line, where we have no less than 9 kilometres. No embankment could in my opinion be constructed of these salty marls and bitter clays which could hold up water for any length of time.

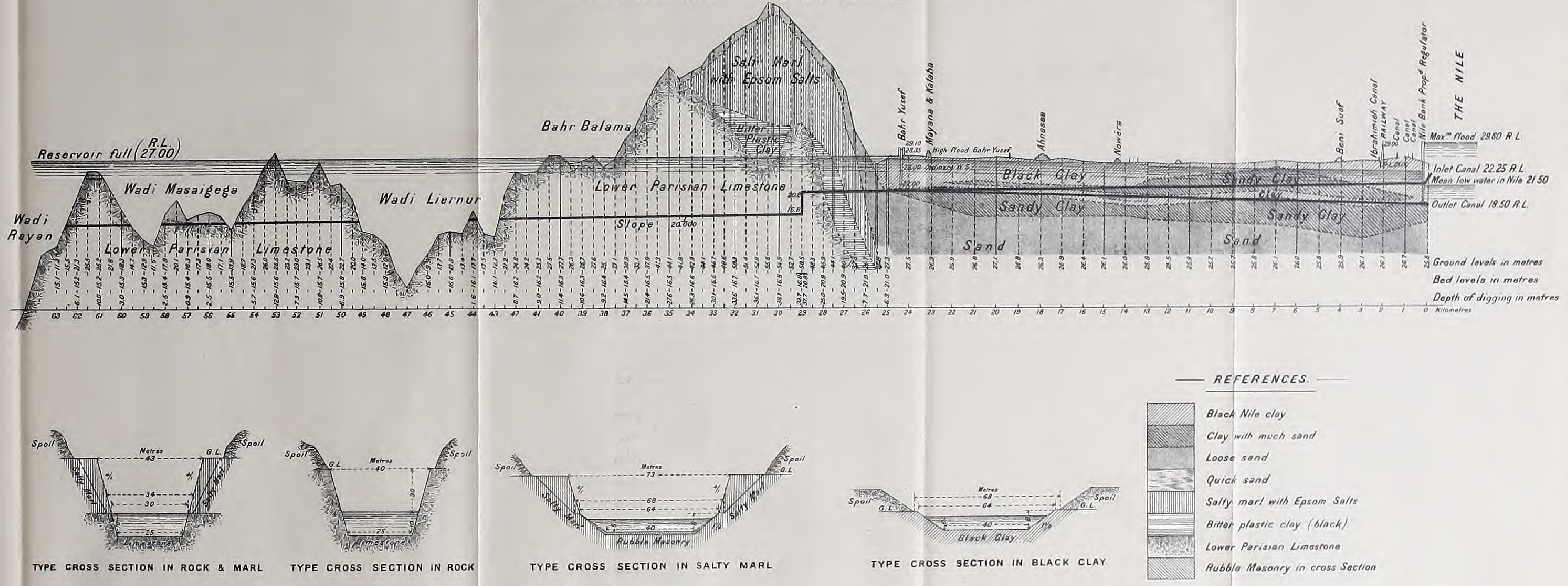
A narrow neck of land, some 15 kilometres in length, runs between the Fayum and the depressions traversed by the Wadi Rayan canal. This neck of land is in continuation of the salty marls and clays, but the limestone is near the surface and is overlaid with a thin skin of sand and pebbles. Its northern slope is covered with the Nile *corbicula* shells at a level of about 22·50 metres above mean sea, while the plain at its foot contains strata of compact fresh-water shells. The southern slopes are devoid of fresh-water remains of any kind. It is evident from this that the ancient Lake Mœris which covered the Fayum rose to a level of about 22·50 metres above mean sea, while the Wadi Rayan has never had Nile water in it. The limestone in Wadi Rayan and neighbouring depressions is inferior to that at the Tura quarries, and is strewn thick with nummulites. It is covered in places with rich deposits of gypsum and salt.

The Wadi Rayan Reservoir might be fed from the Nile or the Bahr Yusuf or from both, while it must discharge into the Nile. The Nile in flood runs so frequently at a level below that needed for flood irrigation that, if the reservoir were to depend on what it could obtain in flood, it would be unable to discharge an appreciable

WADI RAYAN RESERVOIR.

LONGITUDINAL SECTION OF PROPOSED INLET AND OUTLET CANALS.

HORIZONTAL SCALE $\frac{1}{150000}$ VERTICAL SCALE $\frac{1}{600}$



TYPE CROSS SECTION IN ROCK & MARL

TYPE CROSS SECTION IN ROCK

TYPE CROSS SECTION IN SALTY MARL

TYPE CROSS SECTION IN BLACK CLAY

SCALE FOR CROSS SECTIONS $\frac{1}{500}$

E. & F. N. Spon Ltd. London

quantity of water in three years out of ten. If reference is made to the Cairo gauges, it will be seen that 1873, 1877, 1880, 1882, 1884, 1888, and 1893 were years in which the flood practically failed to attain R.L. 18·55 metres at Cairo, which is the minimum needed for effective flood irrigation, and that consequently in those years the reservoir would have failed. The remodelling of the basin feeders, recently carried out by Colonel Ross, has also resulted in a lowering of the Cairo gauge by 30 centimetres during the flood. Under these circumstances it is as necessary for the Wadi Rayan to draw its supply of water in winter (when there is never any deficiency) as it was necessary for the Nubian reservoirs. The natural source of supply in winter is the Bahr Yusuf, and, if there were no question of filling the Wadi Rayan between R.L. − 42 and R.L. + 24, we might dispense with an inlet canal for the Nile. The inlet canal will, however, be needed to raise the level of the reservoir to R.L. 24, and make it ready to receive the top film of 3 metres which alone can be effectively discharged. The Bahr Yusuf takes its supply from the Ibrahimia Canal, which has its head at Assiut. The Bahr will be able to discharge 290 cubic metres per second, and be just within its banks in winter, when the weir is constructed across the Nile downstream of the Ibrahimia canal head. The Bahr Yusuf could not carry more than 260 cubic metres per second in winter, *i.e.* 30 cubic metres under full supply, without hurting the lands on its banks; and for a similar reason, the Wadi Rayan reservoir cannot be maintained at a level above R.L. 27 without permanently injuring large tracts of country. Of the 260 cubic metres per second carried by the Bahr Yusuf, about 60 cubic metres per second will be needed for the irrigation of the Fayum and other improved tracts, leaving 200 cubic metres per second (or 17,000,000 cubic metres per day) for the reservoir. By this means we shall ensure the filling of the reservoir *every year* to its full level of 27 metres above sea-level. This is a matter of the greatest importance. Reservoirs which can only ensure a good discharge after high floods, when the supply in the Nile itself is abundant, and which fail after low floods, when the Nile is most in need of water, are not worthy of serious consideration.

We propose joining the Nile to the Wadi Rayan by a single canal leaving the Nile a few kilometres north of Beni Suef and traversing the intervening desert by the Bahr Bilama. At this point the mean low water is R.L. 21·50, and the high flood level 29·60. This canal will act as an inlet canal to the reservoir when it is being filled and having its water surface raised from R.L. − 42·00 metres to R.L. + 24·00 metres. During this time its head will be at R.L. 22·25, and slope $\frac{1}{20,000}$ into the Wadi Rayan. It will be used thus for seven years. After the seventh year, when the reservoir is at R.L. + 24·00, the canal will be deepened from the edge of the desert to the Nile on a slope of $\frac{1}{10,000}$ backwards into the Nile. It will now act as an outlet canal only, for the reservoir will be annually replenished from the Bahr Yusuf independently of the Nile. Plate LXIX. gives a cross section of this line, while Plate XXXIII. and fig. 187 give the plan.

Table 240 gives the areas and contents of the Wadi Rayan Reservoir at different levels. The evaporation will be 2·50 metres vertically per annum, and will be taken in the calculation as 2 metres in one year and 3 metres in the next. With these facts before us, we may calculate the time it would take to bring the reservoir up to R.L. 27·00, assuming that we began to fill in 1873–74.

The inlet canal in flood will discharge 230 cubic metres per second, and the Bahr Yusuf will give 200 cubic metres per second in winter.

230 cubic metres per second = 20,000,000 cubic metres per day.
200 ,, ,, = 17,000,000 ,, ,,

1873–74. No supply in flood.
In winter 135 days × 17,000,000 = 2,300 millions.
The lake would rise to – 16·00, and owing to evaporation would be at R.L. – 19.

1874–75. In flood 90 days × 20,000,000 = 1,800 millions.
In winter 135 days × 17,000,000 = 2,300 ,,

Total . . . . . 4,100 millions.

				R.L.	R.L.
	The lake would rise to			– 1 – 2 =	– 3.
1875–76 like 1874–75.	,,	,,		+ 9 – 3 =	+ 6.
1876–77 ,, 1874–75.	,,	,,		+16 – 2 =	+14.
1877–78 ,, 1873–74.	,,	,,		+19 – 3 =	+16.
1878–79 ,, 1874–75.	,,	,,		+23 – 2 =	+21.
1879–80 ,, 1874–75.	,,	,,		+27 =	+27.

After seven years the reservoir would be in working order. As we shall see in the next paragraph, it will be necessary for the reservoir to have its levels raised annually from R.L. 24 to R.L. 27. This means 2,000,000,000 cubic metres of water. During years of low flood the whole of this supply must come from the Bahr Yusuf in winter, which, as we have already seen, is capable of discharging 2,300,000,000 cubic metres. During flood the daily evaporation off the lake will be (650,000,000 × ·008) = 60 cubic metres per second, which can be spared from the Bahr Yusuf so as to maintain through the flood the level of the reservoir at a constant level.

We now come to the discharge from the Wadi Rayan Reservoir. In the matter of discharge this reservoir is handicapped as compared to the Aswan Reservoir. It could supply a heavy discharge in May, but owing to the decreasing head, less in June and still less in July; while we want more water in July than in May. The Aswan Reservoir having its sluices above the summer level of the Nile, can discharge much or little as required.

[TABLE

TABLE 240.—CONTENTS OF THE WADI RAYAN RESERVOIR.

R.L.	Area in millions of square metres.	Cubic Contents in millions of cubic metres.	R.L.	Area in millions of square metres.	Cubic Contents in millions of cubic metres.
+30	727	20,843	Sea-level 0	301	6,142
29	709	20,125	−1	294	5,844
28	691	19,425	−2	287	5,554
27	673	18,743	−3	280	5,270
26	654	18,080	−4	273	4,993
25	636	17,435	−5	266	4,723
24	621	16,806	−6	260	4,460
23	607	16,192	−7	253	4,204
22	592	15,592	−8	246	3,955
21	577	15,008	−9	239	3,713
20	563	14,438	−10	232	3,478
19	546	13,886	−11	225	3,249
18	530	13,348	−12	218	3,028
17	513	12,827	−13	211	2,813
16	497	12,322	−14	204	2,605
15	480	11,833	−15	197	2,404
14	464	11,361	−16	191	2,211
13	447	10,905	−17	184	2,023
12	431	10,466	−18	177	1,843
11	414	10,043	−19	170	1,670
10	398	9,637	−20	163	1,503
9	388	9,244	−21	152	1,346
8	379	8,861	−22	142	1,199
7	369	8,487	−23	131	1,062
6	359	8,123	−24	120	937
5	350	7,769	−25	109	822
4	340	7,424	−26	99	718
3	330	7,089	−27	88	624
2	320	6,764	−28	77	542
1	311	6,448	−29	66	470
			−30	56	410
			−35	38	174
			−40	22	22

Between R.L.+24·00 and R.L.+27·00 the Wadi Rayan Reservoir contains 1,937,000,000 cubic metres. One-third will be lost by evaporation and loss of slope in the canal, leaving 1,300,000,000 to be utilised. The proposed canal could discharge this by giving 250 cubic metres per second in May, and 150 cubic metres per second in July. If it was desired to ensure 250 cubic metres per second in July, it would be necessary to widen the canal, which would cost £750,000 more than the estimated cost of £2,280,000, or raise the total to £3,000,000.

We will return now to the details of the design:—

The inlet canal will have a bed width of 40 metres and side slopes of 1 to 1½. At the 29th kilometre of the canal, as proposed by Colonel Western, there will be a vertical drop of 4 metres, as we are here on rock; the bed will be reduced from

40 metres to 25 metres, since it is warranted by the discharging capacity of the section.

The masonry works will be :—

1. Regulating Head.
2. Bahr Yusuf Crossing and Regulator.
3. Ibrahimia Canal Syphon and Railway Bridge.

The project will cost £2,280,000.

Abstract of Cost.

Excavation, inlet and outlet canal combined . .	£1,684,000
Masonry works	225,080
Masonry lining	43,750
Pitching	90,000
Closing depression	1,200
Land	30,000
	£2,074,000
Contingencies	206,000
	£2,280,000

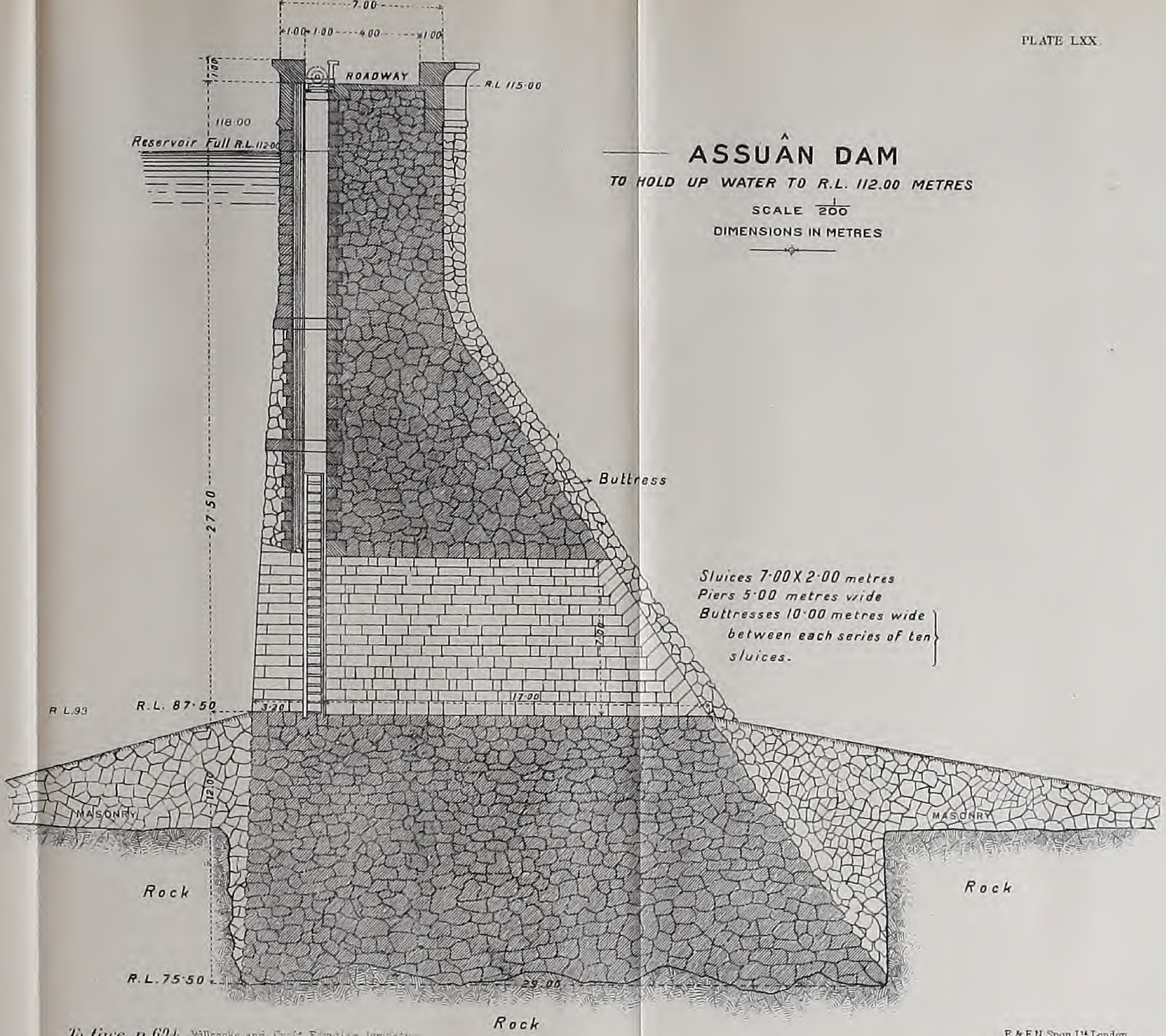
Details of Cost of Excavation.

Inlet and outlet canal combined in	clay,	9,480,000 at	£·04	=	£379,200
,, ,, ,,	marl,	7,592,000 at	·06	=	455,520
,, ,, ,,	rock,	8,374,000 at	·10	=	837,400
,, ,, ,,	sand,	602,000 at	·02	=	12,040
					£1,684,000"

133. **Historical.**—Fifteen years ago a few far-seeing men saw clearly what all of us understand to-day; but among the few no man had greater faith in the future of the country than Sir Ernest Cassel. The Aswan Reservoir project had been lying buried for four years in official pigeon-holes, when in 1898 Sir Ernest came forward with the funds, and with Sir John Aird & Co., as contractors, and Sir Benjamin Baker as Consulting Engineer, undertook to complete the Aswan dam and the Assiut Barrage by December 1903. The Egyptian Government, advised by Sir William Garstin, accepted his offer, and received the completed works by December 1902.

The reservoir was filled in 1903, and gave universal satisfaction. In February 1904 one of us gave a lecture before the Khedivial Geographical Society, entitled *Lake Mœris,* in which it was proposed to raise the Aswan dam on its own base from R.L. 106 to R.L. 112 metres and double the storage capacity of the reservoir. From this lecture the following extracts are given :—

"The Aswan Reservoir at its present level contains one milliard of cubic metres of water, which will suffice for the conversion of half a million acres to perennial



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irrigation. But though the dam was only completed at the end of 1902, already the whole of the water has been devoted to special tracts, and the Government is reluctantly compelled to refuse all applications for water. This has been an unexpected blow to the country, which had been waiting patiently these six years for the long-promised reservoir. While the whole world is crying for that long-stapled cotton which in its highest grades is the speciality of Egypt, the Egyptian landowners of 1½ millions of acres are compelled to wait perhaps for many years, while every country under the sun which can grow cotton is trying to acclimatise their special product, and they themselves are doomed to sit idle.

And yet the provision of the remaining three milliards of water is well within the competence of the country.

At the time of designing the dam, I intended that it should be of such a section that it could be raised 6 metres in height and hold up another milliard of cubic metres of water. Such an operation, if performed to-day, would mean: the whole length of the dam being raised 6 metres, the winches working the sluice gates being raised 6 metres and provided with new wire ropes, and new copings being given to the parapets. It would necessitate two more locks and three more lock gates, and nothing else. The expenditure incurred would be £500,000. See Plate LXX.

One has frequently heard it objected to the raising of the dam by 6 metres that the theoretical pressures at the toes of the structure would exceed 5 kilograms per square centimetre, the maximum pressure proposed by the International Commission. This pressure was proposed by Signor Torricelli as the structure was a new kind of dam, and he stated that until it were tested extreme caution should be adopted. The Gileppe dam in Belgium, which is 47 metres high, has a toe pressure of 10 kilograms per square centimetre. The Khamis dam in Algeria has 11 kilograms. Professor Rankine considered pressures between 7½ and 10 kilograms as quite safe for dams 48 metres high.

When the Aswan dam will have been raised, we shall be standing on the threshold of what it will be able to do. The projected Wadi Rayan Reservoir, or the modern Lake Mœris, will be well able to supply the two remaining milliards of cubic metres of water when working in conjunction with the Aswan Reservoir. The great weakness of this projected lake has lain in the fact that *by itself* it can give a plentiful discharge in April and May, less in June, and very little in July, and it was for this reason that in my report of 1894 to the Egyptian Government I had reluctantly to recommend that it be not carried out. But when the Aswan Reservoir is capable of supplying two milliards of cubic metres of water it will be possible to utilise the Mœris Lake to its utmost capacity. The Aswan Reservoir, being high above the level of the Nile, can give its supply at the beginning or end of the summer; it can give it slowly or with a rush; while the projected Lake Mœris being directly in communication with the Nile, and only slightly above low Nile level, its discharge would depend entirely on the difference of level between it and the Nile, and consequently as the summer advanced it would gradually fall and would not be able to give at the end of the summer a quarter of the discharge it could give at the beginning.

But let us imagine that the reservoir and the lake are both completed and full of water, and that it is the 1st of April. Lake Mœris will be opened on to the Nile and give all the water needed in that month, while the Aswan Reservoir will be maintained at its full level. In May Lake Mœris will give nearly the whole

supply and the reservoir will give a little. In June the lake will give little and the reservoir much ; while in July the lake will give practically nothing and the reservoir the whole supply. Working together in this harmonious manner, the reservoir and the lake, which are the true complements of each other, will easily provide the 4 milliards of cubic metres of water needed for Egypt.

I have already explained how the lake will work in conjunction with the Aswan Reservoir. It remains to explain how it will be fed and how it will discharge its water into the Nile, what the project will cost, and how many years the lake will take to be filled and to be ready for aiding the low supplies of the Nile. In 1894, when the last calculations were made, I had a great advantage over Colonel Western in that it could be assumed that the Assiut weir across the Nile would be in existence and capable of aiding the Lake Mœris Canal. We now have a very much greater advantage than in 1894. Thanks to Sir Hanbury Brown and Mr Webb, we can assume that both the Assiut and Delta Barrages can be used not only in summer but also in flood and winter. Just as the existence of the raised Aswan Reservoir will have rendered the emptying of the lake a simple matter, so the power of using both weirs in flood will have rendered the question of the filling of the lake an easy problem.

The lake can be used as a reservoir holding two milliards of cubic metres of water. The water contained between a surface 27 metres above mean sea and a surface 3 metres lower will be capable of being discharged annually into the Nile by gravity. If more is needed than this from the lower lake, it will be possible to discharge another milliard at a rate of 200 cubic metres per second by means of powerful pumps. Such pumps would cost £250,000 to erect, and £35,000 per annum to work. Twelve years ago such pumps were unknown in the world.

I have been reminded by Mr J. S. Beresford, C.I.E., formerly Inspector-General of Irrigation to the Government of India, and a believer in the Lake Mœris project, that if a plentiful supply of water in the Yusufi Canal could be assured in the winter, it would be possible to utilise the outlet canal as a feeder canal in flood from the Nile, and that even after the lake was full and beginning to discharge back into the Nile. It would be possible to use the Yusufi Canal water to flush the canal and sweep away annually the flood silt deposits and so ensure the canal being ready to act as an outlet canal in April. This suggestion is a truly good one.

The rates allowed for the excavation work are considered too low by some critics. At the hill of salted marl it will be possible to employ the American system of excavating by the aid of water issuing from nozzles under pressure. By this method it will be possible to do such work at P.T. 2 and P.T. 3 per cubic metre as it is done in America. We have allowed P.T. 5 per cubic metre. To this hydraulic pressure work the salted marls will be specially suited, and indeed the recollection of the ease with which Amenemhat dug his canal through this very material lasted long in the memory of Egyptians. Some 1600 years after the canal was excavated, Herodotus was informed that the excavated material was thrown into the canal and transported by the running water. A 12-inch pump on the Yusufi Canal lifting water on to the top of the hill, a number of spade-men helping the water as it coursed down the hill and leading the liquid mud along wooden troughs into side ravines and depressions, and a steep slope on the western half of the hill where the rock had been blasted away, would soon remove all the material

required at a very low cost. We have allowed P.T. 10 per cubic metre for the soft limestone.

In the 1894 Report we had anticipated difficulties with the canal running through the salted marl. Since then I have thoroughly inspected the ravines in the Fayum and seen the El-Bats ravine where it cuts through many kilometres of this very salted marl. The sides are absolutely vertical, and deposits of mud and self-sown tamarisk bushes protect the vertical sides at places where the running water is nearly touching the marl. Such natural protection will be far superior to the masonry lining proposed and far more effective. It will moreover cost nothing.

If we wish not only to irrigate the whole of Egypt but to keep the main branches of the Nile well supplied with water through the twelve months of the year, we must regulate the supply issuing from the vast lakes which constitute the sources of the Nile; we must ensure its passage through the great swamp regions; allow it of its superabundance to bless all the arid lands between the 10th and 24th parallels of latitude; and finally see it enter Egypt a much diminished but still powerful stream of water.

The Nile during high floods is considerably above the level of the country, which is protected by embankments stretching from Aswan to the sea. In Upper Egypt a very high flood is 1 metre above the country, in Middle Egypt 2 metres, and the same on the Rosetta branch of the Nile; it is 3½ metres in places on the Damietta branch. The Damietta branch is really a canal and quite unfit to be used in high flood. The wisest policy, I think, would be for the Government to take the Rosetta branch and call it the Nile, and regulate on the Damietta Barrage just as though the Damietta branch were an ordinary canal. When we first came to Egypt, we found that the policy was to spread the flood into as many channels as possible and protect the whole of them with tens of thousands of corvée. We changed that and concentrated our energies on the Rosetta and Damietta branches. Now that we can regulate on the head of the Damietta branch in flood, thanks to Sir Hanbury Brown's initiative, we might send the main flood down the Rosetta branch.

The high-level Wadi Rayan Reservoir, when converted into the modern Lake Mœris, will have one great advantage, it will be able to lower a high flood 30 centimetres for fifty days. This will give relief to the Nile—a relief which will be much appreciated by the whole country from Beni Suef to the sea, and by Cairo.

We have already said that we should regulate on the Damietta branch and treat that branch like a canal. The whole of the energies of Lower Egypt could then be concentrated on the Rosetta branch, which is very capacious and capable of great development. The frequent breaches on the Damietta branch have been, among other causes, a great cause of the silting up of its bed and sides. The Rosetta branch has had only one real breach in fifty years.

It has been estimated that the completion of development work on the Rosetta branch, considering it the future Nile, would amount to £600,000; while the works on the Damietta branch, considering it a large canal, would cost £300,000. The whole Delta would therefore cost £900,000 for spurs and banks, while the training works would largely pay for themselves, in addition to greatly improving the channel and lowering the level of the flood.

In Upper Egypt there are 50,000 acres of sandy foreshore to be reclaimed and made worth £50 per acre by Eads' method of training, whose reclamation should be undertaken and which it would pay the Government to do. In the works of

spurring and throwing back the bank, the cost will be greatly diminished in Upper Egypt by the long stretches of river where the desert comes to the water's edge and by the fact that stone in Upper Egypt is cheap. A sum equal to that for Lower Egypt would be amply sufficient to train thoroughly the Nile south of Cairo."

In 1904 was published Sir William Garstin's *Report on the Basin of the Upper Nile*, already referred to on p. 129.

In the first appendix to his Report on the Upper Nile, Sir William drew up a programme of works for water storage and flood control in the Nile Valley. He approved of the raising of the Aswan dam for £500,000, and the conversion of the Rosetta branch of the Nile into a flood escape for £900,000. He then conditionally approved of a proposal suggested by Mr J. S. Beresford, C.I.E., for making a straight cut from Bor on the Albert Nile to the mouth of the Sobat River at the tail of the Albert Nile. The line would be 340 kilometres in length and was estimated to cost £5,500,000, and carry 600 cubic metres per second in summer. In case of the line being found impracticable when it was surveyed and levelled, Sir William proposed abandoning the Albert Nile and thoroughly widening and deepening the Zeraf River for £3,400,000.

We now quote from the *Report on the Basin of the Upper Nile* :—

"No examination of the different measures possible for improving the water-supply of Egypt can be complete, without taking into consideration those schemes proposed for this purpose by Sir William Willcocks. These are of such importance that I will give them precedence over all others.

They are three in number :—

(i) The raising of the Aswan dam, thereby increasing the storage capacity of the Nile reservoir.

(ii) The utilisation of the depression known as the Wadi Rayan, for a secondary reservoir, to augment the summer supply of Northern Egypt.

(iii) The remodelling of the Rosetta branch of the Nile, so as to render it capable of serving as a flood escape for the river.

As regards number (i) and (ii), neither of these proposals, as it stands, can be said to be absolutely novel. A dam at Aswan, raised to a height greater than that now suggested, was proposed by Sir W. Willcocks himself, in his original report upon the storage of Nile water. Again, the idea of making use of the Wadi Rayan as a reservoir is due to Mr Cope Whitehouse, who, for years, urged this project upon the Government. The combination of the two schemes, making the one the complement of the other, as now proposed, is, however, an entirely novel idea.

Sir William Willcocks proposes to increase the height of this dam to such a level that the maximum water surface in the reservoir will be raised by 6 metres, *i.e.* from R.L. 106, as at present, to R.L. 112, in the future. This, he calculates, will double the storage capacity of the reservoir, making it capable of containing 2 milliards of cubic metres of water.

I will commence my remarks by saying that I have, hitherto, opposed the immediate execution of this work. For this attitude on my part I shall afterwards give my reasons. For the present, I will only say that, if this project shall be

considered as forming a portion of a definite programme, and *if it be executed in conjunction with others that I shall name*, under such conditions, I withdraw my opposition, and recommend that it be carried out. I will further say that I consider it to be a desirable project, and one that will render undoubted service to Egypt. The scheme has this great advantage over all others, that it is the one from which the earliest returns can be anticipated, and the cost of construction cannot be considered as prohibitive. Use could be made, in Lower Egypt, of the extra water thus stored, in a comparatively short space of time, without waiting until the necessary remodelling of the Upper Egypt basin system had been completed.

I have made it a condition of withdrawing my opposition to this project, that it should be carried out in conjunction with other schemes. These are two in number. The one is the improvement of the Upper Nile, so that an increased summer supply may be brought down, thereby, to Egypt. The other is the provision of sufficient escape power for the river when in flood. Both these schemes are, to my mind, indispensable, and should the Egyptian Government decide to raise the dam, it should also commit itself to the simultaneous execution of both these works.

The Wadi Rayan scheme may, I think, be given a place secondary to this other. When, at some future time, the question of reclaiming the lakes in the northern Delta shall, as it surely will, become a pressing one—then the Rayan project will probably prove to be the best means of securing the increased supply.

Before leaving the question of the Wadi Rayan, I should say a few words regarding its value as a possible flood escape for the Nile. In many respects this depression would constitute an ideal receptacle for such a purpose; but, as Mr Webb points out, the section of the inlet canal, to be of any real use in reducing the height of the flood, would require to be even larger than that which would be required merely to fill the reservoir.

The late Colonel J. C. Ross, formerly Inspector-General of Irrigation in Egypt, stated as his opinion, that in any calculations for the size of the Nile flood escape channel, the minimum discharge to be allowed for should be 100,000,000 metres cube per diem.

Such a discharge would necessitate a canal of very large section. Any such work would involve a very heavy expenditure, which would only be warranted were no other means of providing for the escape of the flood water possible.

Other means do exist, and this brings me to the third and last proposal.

Sir William Willcocks, in his recent paper, urges that both branches of the river should be put into such order that the danger from a flood passing down would be largely diminished. He further proposes that the section of the Rosetta branch shall be brought to a uniform width, by means of spurs, and the banks thrown back, where necessary, so that this channel shall be able to carry a much larger discharge, without danger to the country, than is at present possible. He would then, in flood, regulate upon the Damietta Barrage, treating this branch, as he says, like a large canal, and turning the surplus water down the improved Rosetta branch.

The question of regulating upon the Barrage on the Damietta branch, in a dangerous flood, is one that has long been recognised by us all as a necessity in exceptional cases. All that would, however, be necessary, with regard to this channel, would be so to regulate it that the discharge passing down did not exceed that of a normal flood. This it could certainly stand, as at present, without any

serious risk of danger to the country from a breach in the banks, more especially if a sufficient sum were spent in strengthening them and in improving the training works.

As regards the Rosetta branch, if it is to act as a flood escape—and I agree with Sir William Willcocks in advising that it should be made to do so,—then, as he says, it must be put in thorough order, and remodelled throughout its length.

It is needless to enlarge upon the danger to Northern Egypt during those times when the flood passing the Delta Barrage assumes exceptional proportions. The question is a most important one. Many years have elapsed since a dangerous flood has occurred, and few of the officers now in the Irrigation Department have witnessed one. Another high flood is certain to arrive, and will probably come sooner than later, as all experience shows that the periods of time between dangerous floods do not comprise a large number of years. The damage that a breach in the bank would cause is incalculably greater now than it would have been twenty, or even fifteen years ago. The improvement in, and the extension of, cultivation, the increase of population, and the rise in the value of the land all make this a certainty. I recommend then that a sum of money be devoted to the improvement of both branches of the river, north of the Barrage—particularly with the object of so improving the Rosetta branch that it can carry off the surplus water of a dangerous flood without risk to the country.

Sir William Willcocks estimates the cost of these works at £900,000. If an efficient flood escape can be secured for this sum, the result will have been cheaply attained.

It will be seen from the foregoing that I recommend the raising of the Aswan dam and the improvement of the Rosetta branch. I do not recommend the present utilisation of the Wadi Rayan as a storage reservoir, for the reasons that I have given above.

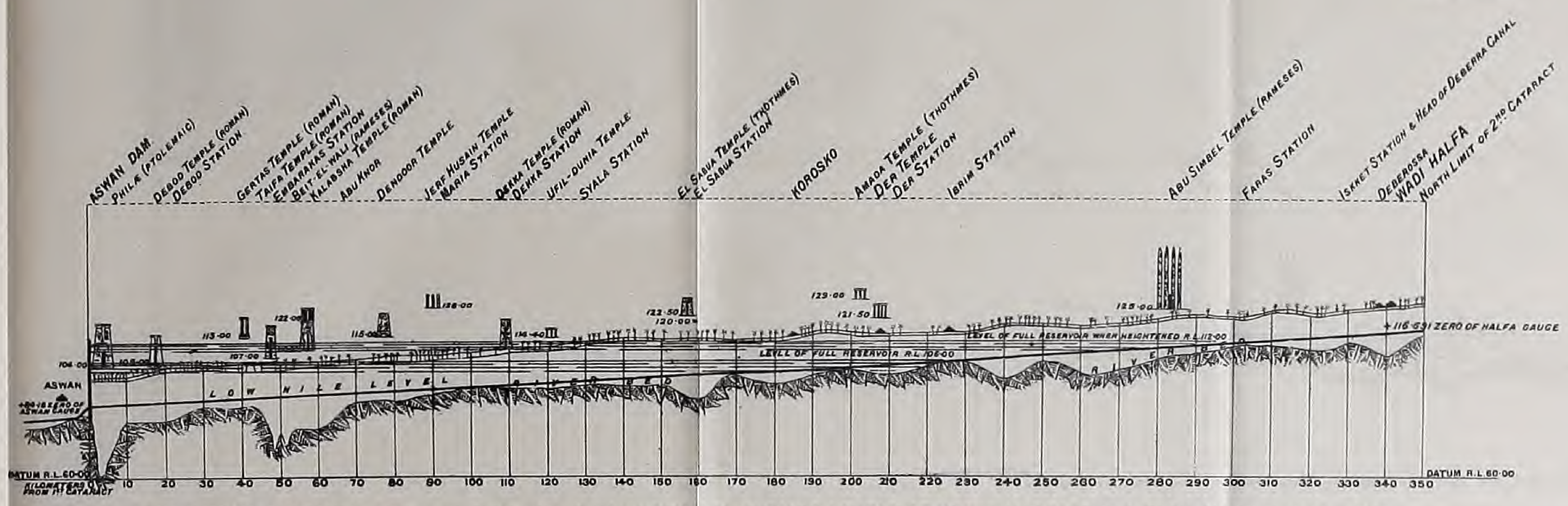
I further urge, in addition to the two projects mentioned, that the improvement of the Bahr el Gebel should be put in hand, and that the water supply of the Nile reaching Egypt in winter and in summer should be increased by one or other of the methods that I have suggested in my report."

At the time that this Report was written, Mr Craig, who had accompanied Sir William Garstin on his journey from the Albert Lake to Khartoum, suggested the construction of three reservoirs: (1) at the junction of the Pibor and Baro Rivers, (2) at Lake No, and (3) on the White Nile.

Acting on Sir William Garstin's advice, the Government spent many hundreds of thousands of pounds on strengthening the Nile banks and the spurs ; but, owing to regulation on the Barrages in low floods, the rise of the bed levels of the branches, especially the Damietta branch, has, we are afraid, gone far to counteract this excellent work.

Early in 1905 Sir Benjamin Baker, Consulting Engineer to the Egyptian Government, negatived the proposal to raise the Aswan dam on its own base, and Sir William Garstin abandoned the idea. He, however, published this notice in the *Journal officiel* of the 15th March 1905 :—

"In my recent report upon the Upper Nile basin I discussed Sir William Willcocks's proposals and agreed with him in recommending that the existing dam



LONGITUDINAL SECTION OF THE NILE FROM ASWAN TO WADI HALFA SHEWING LEVELS OF WATER IN RESERVOIR AT R.L.106·00 AND R.L.113·00

CONTENTS OF RESERVOIR AT R.L.106·00 980,000,000 M3
" " " " R.L.113·00 2,300,000,000 M3

—— HORIZONTAL SCALE 1:400,000. ——
—— VERTICAL SCALE 1:2,100. ——

NUBIAN TEMPLES

Nº	NAME OF TEMPLE	PERIOD	KIL^S FROM DAM	R.L. OF TEMPLE	UNAFFECTED BY R.L.113·00	AFFECTED BY R.L.113·00
1	PHILÆ	ROMAN	3	104·00		AFFECTED
2	DEBOD	"	18	105·00		"
3	GER	"	40	115·00	UNAFFECTED	
4	TAIFA	"	48	107·00		AFFECTED
5	KALABSHA	"	56	110·00		"
6	"	EGYPTIAN	56	122·00	UNAFFECTED	
7	DENDOOR	ROMAN	77	115·00	"	
8	JERF-HUSAIN	EGYPTIAN	90	126·00	"	
9	DEKKA	ROMAN	108	110·00		AFFECTED
10	UFIL-DUNIA	"	122	114·40	UNAFFECTED	
11	EL SABUA	EGYPTIAN	167	120·00 122·50	"	
12	AMADA	"	203	123·00	"	
13	DER	"	208	121·50	"	
14	ABU SIMBEL	"	283	125·00	"	

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should be raised 6 metres above the present maximum level permitted in the reservoir. Before making this proposal, I had satisfied myself, through the calculations made by Mr Webb (now Sir Arthur Webb) and his engineers, that *according to all accepted theories regarding dam constructions*, the factor of safety was sufficient to permit of the dam being raised to the proposed height, without risk of failure to the structure."

At the beginning of 1907 Sir Benjamin Baker proposed widening the dam by 6·5 metres on its downstream side and raising the water surface to R.L. 113·00 instead of R.L. 112·00. Sir William Garstin accepted the proposal. The work of widening and raising was begun in 1907, and completed in December 1912. See Plate LXXI.

During the winter of 1906–7 Sir William Willcocks journeyed from Khartoum to the Equatorial lakes, and on his return gave two lectures before the Khedivial Geographical Society in December 1907 and January 1908, entitled *The White Nile and the Cotton Crop, I. and II.* They were devoted to the subject of water storage and flood protection as affected by our more intimate knowledge of the White Nile. We give extracts from them :—

The First Lecture.

"Opinions may differ as to the future of the countries on the upper waters of the Nile, and as to the crops and industries they may eventually adopt; but there is little doubt that in Egypt and the Sudan no crop will compete with cotton for many years. The sugar-cane crop south of Assiut in Egypt may, however, hold its own against cotton. In the Sudan wheat may compete with cotton, but give free irrigation opportunities to the country and cotton will be found to have no serious competitor. For such cotton in Egypt and in a great part of the Sudan, irrigation is a necessity: in the Sudan between the 15th of May and the 15th of March, and in Egypt between the 15th of March and the 15th of October. Water is needed everywhere between the 15th of May and the 15th of June, and it is just then that the Nile supply is at its lowest.

It is for this reason that the necessity of water storage for the development of the cotton crop is of such commanding interest in both the Sudan and Egypt. In the Sudan, except on a few favoured and restricted estates, the authorities prevent your taking water from the Nile from the 1st of February to the 15th of July. The 15th of July is St Swithin's Day, and though you may begin to irrigate on that day, it is too late for the saint to see the cotton crop through its difficulties.

The White Nile from its source to its mouth is a series of reservoirs. In its natural condition it stores immense quantities of water, and we have noted that there are three sites particularly suited for artificial reservoirs. They are Nimulé near Lake Albert, the Sobat mouth, and Khartoum. It is only necessary to so regulate these existing reservoirs that they may give their waters when we need them, and not when they naturally do.

Of the necessary works, the most convenient to undertake first would be the regulation of the White Nile near Khartoum. Two earthen banks about 5 kilometres apart, pitched with stone, stretching across the valley, each pierced by a

lock and barrage similar to the one under construction at Esna, though with only thirty openings each and not one hundred and twenty, as at Esna, would, I roughly calculate, hold up between them 8 metres of water, and form a reservoir containing anything between 2½ and 3½ milliards of cubic metres of water. The advantage of having the works near the tail of the White Nile would lie in the fact that the discharged waters would immediately flow into the Nile and hurry on to Egypt. By discharging the water early in the summer and keeping the Aswan Reservoir full as long as possible, there would be a minimum of loss by evaporation.

Similar, but much smaller, works than those needed near Khartoum would be required for the reservoir at the Sobat mouth, though they would probably cost as much. The impounded waters, when set free, would have to flow down the last 840 kilometres of the White Nile before they reached Khartoum, and the losses would be heavy. The Khartoum site is the better of the two.

The dam at Nimulé must of necessity wait till the two reaches of the White Nile above and below the rocky pass south of Gondokoro have been connected by a railway, and till the dredgers in the Sudd region have made the river capable of carrying on the supply. Such a work, discharging 1200 cubic metres a second as a maximum, of absolutely clear water, would be a simple work, and even in the inhospitable regions of Lake Albert would cost considerably less than £1,000,000. Its interest to-day is, however, academic."

The Second Lecture.

"The White Nile from Khartoum right up to Lake No is, as has already been pointed out, very nearly a lake in flood, and would stay a lake for ever if the Blue Nile were subject to a perpetual flood. Between low summer and high flood there is a difference of 8 metres. We want a masonry work or masonry works which will keep this impounded water where it is when the Blue Nile has fallen and deliver it just when we need it—not superabundantly in the latter half of October, November, and December, and in deficiency in April, May, and June, but *vice versa.* A barrage with thirty openings, like the Esna Barrrge, built at the point of junction of the Blue and White Niles, and holding up 4½ metres of water, and a second higher up the White Nile near Gordon's Tree, impounding another 3½ metres, would between them form a reservoir of extraordinary magnitude. The reservoir would contain some three milliards of cubic metres of water, and with the Aswan Reservoir would suffice for Egypt and the Sudan for many years. If this combination were not considered the best, a combination of a barrage at the junction of the Blue and White Niles with another at the Abu Zeid ford, would form a still more powerful reservoir. Then there is the Sobat mouth, which is available. A combination of the three sites would bring us to the conceptions of the builders of the Pyramids and the constructors of Lake Mœris. Not only could we store all the water needed for Egypt and the Sudan, but I believe we could have such an effect on a very high Nile that the dangers of an inundation would materially be decreased. We are on the threshold of as wonderful and startling discoveries as any made by any hydraulic engineers in the world.

It will, however, be an evil day for Egypt if she thinks that, though basin irrigation with its harvest of corn has given way to perennial irrigation with its cotton fields, the lessons which basin irrigation has taught for seven thousand years can be unlearned with impunity. The rich muddy water of the Nile flood has been the

mainstay of Egypt for many generations, and it can no more be dispensed with to-day than it could be in the past. In good lands, suitable manures and crop rotations will enable us to dispense with liberal washings with the muddy waters of the Nile flood; but in all poor lands, and certainly in all salted lands, no manure or rotation of dry crops can take the place of occasional or frequent rotations of rice when the flood waters wash out the salts and leave their rich sediment on the land. Rice is a connecting link between perennial and basin irrigation, and is as necessary to ensure the production of high-grade cottons in quality and quantity for many generations as was ever basin irrigation for the insurance of the corn harvests of the Nile Valley from deterioration."

In November 1911 one of us lectured before the Egyptian Institute on the subject of securing a ten-million kantar cotton crop for Egypt. The lecture was entitled *A Ten-Million Kantar Cotton Crop*, and from it we quote the following:—

"I bring this lecture to a close by calling attention, as I invariably do, to the necessity of insuring the cotton crop against the danger of an inundation. All this wealth which is being built up and to be built up will lie at the mercy of the first very high flood like 1878. In the matter of insuring the country against the terrible evils of an inundation we ourselves are sitting at the same gate of God at which sit the fellahin when they contemplate the cotton worm. By its barrages, Egypt has been insured against all but very extraordinary years of drought. For years of high flood no provision has been made. The foundation-stone of the Mesopotamian project is an escape for the excessive floods of the Euphrates. In the project for the Aswan dam, I refused to separate the question of providing water for perennial irrigation from the question of protecting the irrigated lands from inundation. Having been in personal charge of long reaches of the Nile bank during the floods of 1887, 1892, and 1894, I can never forget the danger the country incurs whenever there is a really high flood; and we have never seen floods like those of 1874 and 1878.

The great rulers of the Twelfth Dynasty, the Amenemhats and the Usartsens, by the construction of the Lake Mœris escape, protected the Egypt of their day from the dangers of a high flood. The Egypt of our day is wealthier far than ancient Egypt, and has its wealth far more exposed to the dangers of an inundation. With their towns and villages built on high mounds and the basins full of water, the ancient inhabitants of the country thought it worth their while to protect their restricted enclosures, gardens, and country-houses from being overwhelmed by a flood. To-day the towns and villages stand in the open country surrounded by endless fields of cotton and maize hurrying to maturity just when the flood is at its highest; and when the river has reached a certain height, each bank has as its real protection a breach in the other bank.

The proposed Wadi Rayan escape would, if carried out, protect the cotton crop from a too early flood and the whole of Lower Egypt from a very high flood. Two weirs on the White Nile, one at Omdurman, the other at Gordon's Tree, would materially shorten the duration of every long drawn-out flood and especially of a very high flood."

The Sudan irrigation service was inaugurated in 1904 with Mr C. E.

Dupuis as Inspector-General. The irrigation reports for the different years give detailed accounts of the surveys made and the works undertaken. Mr Dupuis spent £150,000 on the purchase of three powerful dredgers—a dipper, a hydraulic, and a grab—and a tow-boat and six barges for the transport of coal. The above were all designed by Mr A. W. Robinson of Montreal. Tenders were invited in 1907–8, accepted between December 1907 and January 1909, and the dredging fleet arrived between December 1909 and December 1910. Full particulars are given in Mr Dupuis' *Historical Summary of the Construction of Dredgers for the Upper Nile.* Details of the early work are given in Mr E. P. Shakerley's report on p. 247 of the Irrigation Report for 1910.

Mr Dupuis made a cut from the Albert Nile to the Zeraf River, which is depicted on Plates XII. and XIII., and of which an account is given in paragraphs 32, 33, and 36. He began the widening and deepening of the Bahr Zeraf on the lines laid down by Sir W. Garstin (page 698).

In 1910 Mr P. M. Tottenham succeeded Mr Dupuis as Inspector-General, and, in addition to the continuation of his predecessor's work, he devoted himself to the collection of information about the Sudd region and the preparation of a detailed project for a reservoir on the White Nile. His reports have not yet been published, but the broad lines of his proposals are known. He proposes a barrage at Gebel Auli on the White Nile 30 kilometres upstream of Khartoum, which will be founded on rock and form a reservoir impounding 4 milliards of cubic metres of water, of which 1¼ milliards will be lost, leaving 2¾ milliards to be stored in the reservoir. Upstream of that again he proposes a barrage at Gebelein which will store 2½ milliards of cubic metres of water. The White Nile will be stopped at Gebelein, filling the Gebelein Reservoir, while the Gebel Auli Reservoir will, if necessary, be filled by the Blue Nile. We shall thus be able to take 2000 cubic metres per second from the Blue Nile at a critical time and keep the highest Blue Nile floods normal. Water storage and flood control will indeed go hand in hand.

Egypt, however, has already begun to reap a rich harvest of water from the conquest of the Sudan. We have shown on page 204 (paragraph 26) how the summer discharge of the Albert Nile in a very low year has been increased at its tail from 220 to 360 cubic metres per second owing to the keeping of the channel of the Albert Nile through the Sudd region clear of sudd, while some 60 cubic metres per second have been added to the discharge of the Zeraf River, giving a total increase of 200 cubic metres per second. This increase has made itself felt at Wadi Halfa by raising the summer discharge in a very poor year from 250 to 445 cubic metres per second. All this water has come on to Egypt, as none of it has been wasted in filling the trough, and moreover the difference of the water surface of the river between the times when it is carrying 250 and 445

cubic metres per second is so small that the additional losses by evaporation have been insignificant.

In Sir William Garstin's Report of 1904 on the basin of the Upper Nile, Mr Dupuis discussed the question of the capacity of a Lake Tsana reservoir. This reservoir would be used exclusively for irrigation projects in the Sudan Gezira, as none of the works on the White Nile could be utilised for this purpose. This project is considered in paragraph 140 of this chapter.

134. **Summer Supply Requirements of Egypt.**—In the Report for 1894 it was assumed that provision should be made for the perennial irrigation of nearly the whole of Upper Egypt, the cultivated area of Lower Egypt, and the better half of the waste lands of the latter. As the Albert Nile was badly sudded in those days, we could only count on a summer supply in the river of 250 cubic metres per second. Allowing for one-third the area under summer crops, we calculated that a reserve of 3,600,000,000 cubic metres would suffice for the perennial irrigation of the whole of the above area.

With the channel of the Albert Nile kept clear of sudds and the Zeraf River fed at its head by Dupuis' cut, we can now count on 445 cubic metres per second, and moreover the heavy irrigation of these days allows us to add 85 cubic metres per second through seepage, so that our minimum to-day is 530 cubic metres per second as naturally available. The balance has to be supplied by reservoirs.

At the present time the area under perennial irrigation in Upper Egypt is roughly 1,000,000 acres, and in Lower Egypt 3,100,000 acres. The summer crops to-day cover half the area, and Tables 241 and 242 show us that we need 1,300,000,000 cubic metres in the Aswan Reservoir to ensure the summer crops over the existing perennially irrigated area of 4,100,000,000 acres.

TABLE 241.—AREAS IRRIGATED, IN THOUSANDS OF ACRES; AND WATER NEEDED, IN MILLIONS OF CUBIC METRES PER DAY.

Month.	Upper Egypt.					Lower Egypt.					Egypt.
	Winter.		Summer.		Total Water.	Winter.		Summer.		Total Water.	Total Water.
	Area.	Water.	Area.	Water.		Area.	Water.	Area.	Water.		
March	500	7	250	8	15	2000	34	500	10	34	49
April	300	4	450	14	18	1500	18	1300	30	48	66
May	100	1	500	14	15	300	4	1600	35	39	54
June	...	...	500	17	17	...	...	1600	48	48	65
July 1–15	...	...	500	17	17	...	...	1600	48	48	65

A point to which we would draw attention is the increased quantity of water required in April when both winter and summer crops are on the ground. Both in 1912 and 1913 complaints of shortage of water in this month were noticed in the Monthly Bulletin of the Department of Agriculture.

TABLE 242.—COMPARISON OF WATER SUPPLY AND REQUIREMENTS (1912).

Month.	Requirements.		Natural Supply, in cubic metres per second.			Excess. Cubic metres per sec.	Defect to be supplied by Reservoirs. Cubic metres per sec.	Defect, in millions of cubic metres per day.	Equivalents in the periods, in millions of cubic metres.
	Millions of cubic metres per day.	Cubic metres per second.	In River.	Seepage.	Total.				
March .	49	570	690	100	790	220			
April .	66	760	550	100	650	...	110	10	300
May .	54	630	460	90	550	...	80	7	210
June .	65	750	430	80	510	...	240	21	630
July 1–15 .	65	750	800	40	650	...	100	9	140
								Total	1280

We may therefore say that 1,300,000,000 cubic metres of water are needed to supplement the summer supply of the Nile to ensure the irrigation of the actual area in Egypt under perennial irrigation.

The raised Aswan Reservoir contains 2,400,000,000 cubic metres, so that 1,100,000,000 cubic metres are available for the extension of the summer irrigation of Egypt.

Table 243 shows in detail the quantities of water that will be required when the following additional areas have been brought under perennial irrigation:—

Project A. 1,000,000 acres in Upper Egypt.
600,000 acres of waste land in Lower Egypt.
,, B. 1,000,000 acres in Upper Egypt.
1,200,000 acres of waste land in Lower Egypt.
,, C. 1,000,000 acres in Upper Egypt.
1,800,000 acres of waste land and lake in Lower Egypt.

With project A, the perennial area of Upper Egypt will be raised to 2,000,000 acres, and of Lower Egypt to 3,700,000 acres: *i.e.*, the whole of the present perennial area of Lower Egypt and half the waste lands.

With project B, the perennial area of Upper Egypt will be 2,000,000 acres, and of Lower Egypt 4,300,000 acres: *i.e.* the whole of the present perennial area of Lower Egypt and the whole of the waste lands.

With project C, the perennial area of Upper Egypt will be 2,000,000 acres, and of Lower Egypt 5,100,000 acres: *i.e.* the whole of the present

perennial area of Lower Egypt, the whole of the waste lands and the lands now under the lakes.

In calculating the requirements of the waste lands and the lands under the lakes, the duty of summer water is increased from 30 to 40 cubic metres per acre per day as these lands will require a largely increased rice area.

TABLE 243.—WATER REQUIREMENTS, IN MILLIONS OF CUBIC METRES.

Month.	Upper Egypt, per day.	Lower Egypt, per day.			Egypt, per day.			Absolute Requirements of Egypt.		
		A	B	C	A	B	C	A	B	C
March	15	10	20	30	25	35	45	150	460	750
April	18	14	28	42	32	46	60	960	1380	1800
May	15	11	22	33	26	37	48	800	1150	1490
June	17	13	26	39	30	43	56	900	1290	1680
July 1–15	17	13	26	39	30	43	56	450	650	840
							Total	3260	4930	6560

As the Aswan Reservoir has a surplus of 1,100,000,000 cubic metres to meet part of these requirements, they may be reduced to the following figures :—

Project A. 2,200,000,000 cubic metres at Aswan.
Project B. 3,800,000,000 ,, ,,
Project C. 5,500,000,000 ,, ,,

The above quantities will have to be supplied by additional works. If the water is stored far away from Egypt, allowances will have to be made for losses on the way down.

135. **Utilisation of the Sudd Region of the Nile.**—During January and February 1912 one of us, and in April 1913 the other, carefully inspected the Sudd region of the Albert Nile and Zeraf River under the guidance of Mr Shakerley, by the kind permission of Mr Tottenham. We have come to certain conclusions which have been partly given in CHAPTER III., and which we shall elaborate here :—

(1) We note first of all that the keeping open of the channel of the Albert Nile through the Sudd region not only has resulted in an appreciable increase in the width of the channel in congested reaches, but also has greatly increased the discharge in low water. This effect is given in detail in paragraph 32. Where in April 1900, in a very low year, the Albert Nile was discharging 220 cubic metres per second into Lake No, in the equally low year 1912 it was discharging 360 cubic metres per second in February, and fell to 325 in August when the Sobat threw back water on the river.

(2) We think that if some species of harrow dredger were designed which would plough up the bed or sides of the channel from Lake No upwards, the nearly clear water of the Albert Nile would carry the stuff forwards, and, aided by a little manipulation, deposit most of it in Lake No. Downstream of Lake No, the same process should be continued by other harrows and the current be induced to part with most of the stirred-up stuff in the large "mayas" or lagoons which are encountered. We had the opportunity of discussing the subject with Mr A. W. Robinson of Montreal, who has already designed the dredgers for the Sudd region, and he said he could design such a dredger.

(3) We consider that the Sudd region is traversed by the Albert Nile as a deltaic stream, with the water generally higher near the river than away from it: though, every now and then, the water which has left the main stream and flowed through side streams or swamps, collects in sufficient quantity and gains sufficient head on the dwindled parent stream to flow back into it and greatly increase the discharge. This has been noted again and again in paragraph 32. Raising the banks of the Albert Nile in the Sudd region we consider of no value whatever. Every effort should be made to lower the water level in the main river, without, however, depriving it of its efficiency and power to keep clean its channel and scour out its sides. Harrowing up its bed would be the most effective way if it were possible. Where the bed was not composed of the decomposed stuff which makes the sides, and therefore not easily harrowed, the sides should be attacked and the stream widened. Once we have enough of water in the main stream, we can begin widening and deepening the side streams, and notably the Maya Signora, strongly advocated by Mr Tottenham. This old course of the Albert Nile runs from near Buffalo Cape to a point 12 kilometres downstream of Lake No, and would help to lower the water in this reach.

(4) If the harrowing up of the bed and sides of the Albert Nile from Lake No to the Sobat mouth were successful, this work should be pushed on with all expedition. If this reach did not respond, the deepening of the channel by dredging should be one of the first works attempted, especially if it were possible to get the power needed for working the dredger by means of a barrage constructed near the tail of the Zeraf River. Looking at the longitudinal section of the Zeraf, it seems that this might be done while the river was discharging 150 cubic metres per second at its tail, without throwing back water on the first 90 kilometres.

(5) The Zeraf River could be made capable of carrying 150 cubic metres per second in low supply without wasting much more water than it does at present. This is considerably less than the quantity advocated by some engineers; but they propose banks, and we do not believe in long continuous banks in the Sudd region, be it the Albert Nile or any

of its branches. With the same engineers we agree that withdrawing this quantity of water from the Albert Nile at Dupuis' cut would not seriously decrease the discharge of the parent river itself past Hillet Nuêr. More water from the side marshes would find its way into it, or less water wander from it into the side marshes. During low supply the Albert Nile at Dupuis' cut is 1 metre higher than the Zeraf, and could easily feed the Zeraf, while in high supply the flow from the Albert to the Zeraf is quite normal. This is wonderfully convenient in its automatic action, and saves the expense and worry of a head regulator. See paragraph 33.

(6) We do not see any advantage in closing off the spills in the upper reaches of the Albert Nile near Bôr. The side depressions are too wide, too deep, and, in low supply, lie far too low.

(7) It is owing to these same deep depressions that we, on mature consideration, do not consider any regulating works at the outlet of the Albert Nile or at Nimulé would be of any use, at any rate at present. Of every 100 cubic metres per second extra which passed Mongalla, 75 would find their way into the depressions.

(8) We do not believe in deepening or widening the channel of the Albert Nile upstream of Hillet Nuêr. It might lead to loss of storage water during flood, which would leave the Albert Nile altogether and not be available to help the low supply of the river.

(9) Once December has passed, we do not believe in any increase of water anywhere reaching Khartoum in any appreciable quantity. While the river is falling, the side swamps and lagoons aid the river; but when it begins to rise they rob it of great part of the rise.

(10) In order of importance we place the works we propose as follows:—

- (*a*) Harrowing up and deepening the channel from Lake No to the Sobat mouth, notably the upper part of it.
- (*b*) Harrowing up the Albert Nile from Lake No to Hillet Nuêr.
- (*c*) Increasing Dupuis' cut so that it could discharge 150 cubic metres per second in low supply.
- (*d*) Opening up the Maya Signora.

If all the works were fairly successful, we should count on a minimum discharge at the tail of the Albert Nile of 600 cubic metres per second, thus made up:—

Albert Nile proper	450 cubic metres per second
The Zeraf	150 ,, ,,
Total . .	600 ,, ,,

If now the Sobat gave 50, we should have at Malakal, as a minimum, 650 cubic metres per second. If this were done, in the way we suggest,

by steadily letting the discharge fall or be constant from December to May, we might count on 600 cubic metres per second at Khartoum. More than this we do not think can be obtained from the Sudd region in a minimum year.

136. **Reservoirs on the White Nile.**—Any reservoirs on the upper waters of the Sobat River would result in a withdrawing of water from the reservoir which forms naturally every year above the meeting-point of the Albert Nile and the Sobat River (*i.e.* the head of the White Nile) in the months of August, September, October, and November. If this reservoir, which has been urged by Mr Craig since his visit to the upper waters of the White Nile in 1903, were formed by the construction of a regulator on the Upper Sobat, and the water discharged from it methodically so as to maintain the level at Malakal and by no means raise it, it would answer admirably, and prevent any decrease in the discharge of the river in December, January, and part of February.

There remain the reservoirs in the trough of the White Nile proposed in 1907. Mr Tottenham has taken up this question with his accustomed energy, and found the best site for the lower reach of the river at Gebel Auli, some 30 kilometres upstream of Khartoum, and for the upper reach at Gebelein 430 kilometres downstream of the Sobat mouth. These two reservoirs would each contain some 4 or 5 milliards of cubic metres of water with 12-metre high dams founded on rock. Under the heavy evaporation of 14 millimetres per day, this quantity would be greatly reduced, but we might count on a net reserve of 2¾ milliards at Gebel Auli and 2½ milliards at Gebelein, because the water could be sent down early in summer to maintain the Aswan Reservoir at full supply level. The larger the capacity of the Aswan Reservoir the earlier could the water be sent down from these shallow reservoirs. It is for this reason that a reservoir at Aswan capable of holding up 5 milliards of cubic metres of water would be of especial valve. That such a reservoir could be made will be shown in paragraph 138.

137. **Flood Protection with the aid of the White Nile Reservoirs.**—We have so far spoken of the value of the White Nile as a source of summer supply. We now turn to its great value as a source of flood protection for Egypt. In the second lecture on *The White Nile and the Cotton Crop*, the value of the White Nile Reservoir as a means of protecting Egypt in flood time was prophesied (page 702). The subject was brought forward again in the lecture on *A Ten-Million Kantar Cotton Crop* (page 703). Mr Tottenham saw in it the principal function of this reservoir. It has been explained on page 702 how the tail reach of the White Nile in high flood is a lake while the Blue Nile is at its height, and how the reach empties itself as the Blue Nile falls, and maintains a high level in the main Nile after the Blue Nile has

fallen. Now, with a powerful regulator at Gebel Auli for the lower reach of the White Nile, and another at Gebelein for the upper reach, we could keep the upper regulator closed during a very high flood and so force the Blue Nile to send a considerable part of its discharge up the White Nile instead of sending it all on to Egypt. This would greatly reduce the force of the flood. This, however, would be but a part of the aid it would give to Egypt. The more effective work it would perform would be to prevent the White Nile from automatically keeping up the level of the main Nile after the Blue Nile had fallen. With both the Gebelein and Gebel Auli regulators closed, the White Nile would not discharge all its water as the Blue Nile fell, but only that part of the supply which was downstream of Gebel Auli. This even might be delayed a fortnight or three weeks by a regulator across the White Nile at its tail near Umdurman. This would be useful for scouring out Blue Nile water deposits which had formed in the tail reach of the White Nile under the new conditions. The main Nile would therefore fall much more abruptly than it does at present, and the relief afforded to Egypt would be incalculable. After the Blue Nile had fallen a metre, the Gebel Auli regulator could be gradually opened and the flood maintained at a reasonable level and not at a dangerously high level. A considerable quantity of Nile mud would be deposited in the tail reach of the White Nile, but the falling water would keep a channel clear by scouring out the fresh deposit in its way, while it was fresh and capable of easy removal.

138. **Proposal to increase the Storage of the Aswan Reservoir to 5 milliards.**—The raised Aswan dam holds up between $2\frac{1}{3}$ and $2\frac{1}{2}$ milliards of cubic metres of water. We shall now consider the question of increasing the capacity of the reservoir by raising the full supply level from R.L. 113·00 metres to R.L. 120·00 metres.

To look at the massive and imposing dam, one would imagine that it might be raised with ease, but there are certain difficulties in the way which we shall first enumerate and then give the solution we propose.

The addition to the right flank of the dam is badly cracked on its downstream face on a length of some 200 metres where the dam goes down to a depth of 20 to 30 metres below the present water level of the reservoir, and where the foundations of the additional work have evidently settled and separated from the old work. This is shown in detail in paragraph 149. Fortunately the old dam here is 25 per cent. more massive than it need be, and is strong enough to resist the pressure by itself. If a strong earthen bank were placed upstream of the dam in this reach, and the dam itself looked upon as a supporting toe to the bank, it could be raised 7 metres, or

up to R.L. 120·00 metres, without danger. It would not even be unsightly.

At some other sites, notably between openings 121 and 140, there has been a settlement of the foundation, which has increased in the first four months of working, and it would scarcely be safe to raise the dam here to R.L. 120·00 metres. At its present level of R.L. 113·00 the old dam is strong enough to hold its own quite independently of the new work, and is doing so; but if the water surface were raised by 7 metres, it might be dangerous.

When the water surface of the reservoir was lowered to R.L. 106·00 metres out of consideration for Philæ, the openings had to be made as low as possible to discharge as much water as possible. These low-level sluices are quite unnecessary, and there are many of them. They will be a source of weakness to a raised dam. No opening of the dam holding up water to R.L. 120·00 need be lower than R.L. 94·00 metres. Many to-day are at R.L. 87·50.

If we put all these things together, it will be seen that a new dam in the future would be in the end cheaper and infinitely more stable. We therefore propose the construction, on the downstream side of the talus, of a new dam holding up water to R.L. 120·00 metres, which we could build comparatively cheaply and quickly by manipulating the discharge of the river through the different openings for eight months per annum. The talus of the existing dam would be a powerful apron for the new dam and add greatly to its power of resistance. The lock gates could be economically utilised by raising the sill of the head lock by 5 metres. A sum of £4,000,000 would see Egypt possessed of a dam of homogeneous masonry, which would be for all time.

Under these conditions the old dam would not be wasted, but the lessons it has taught would be utilised for the construction of a work which would stamp the British occupation of the country for all time as effectively as the Pyramids have stamped the great days of the early Pharaohs.

We only ask of posterity that the graceful cornices which were designed under clear skies in the shadow of Egyptian pylons be not changed for designs copied from Stonehenge in foggy chambers in Westminster.

Now, it might happen that as land in the Sudan became more and more valuable, the Government of that country might raise objections to the valley of White Nile being sacrificed to provide Egypt with water. It might demand excessive compensation. In this case it would be possible for Egypt to raise the capacity of the Aswan Reservoir to 5 milliards of cubic metres of water, and then the Gebel Auli Reservoir could discharge its water in December, and help to fill up the Aswan Reservoir to R. L. 120·00 metres.* The trough of the White Nile could then

* The floor of Abu Simbel temple is at R.L. 125·00 metres.

be cultivated in a far more effective way than it is to-day. The whole lower reach of the White Nile would become a very valuable basin of some 100,000 acres.

As silt might be deposited in flood upstream of Aswan, during the construction of the lower dam, if both the old and new dam were obstructing the waterway, we propose to overcome the difficulty in the following way. Construction on the lower dam up to floor level and utilisation of the upper or existing dam would proceed together. When the lower dam was up to the floor level of its sluices, it would be possible to dismantle the existing dam and draw the whole summer supply from the White Nile reservoirs. They would contain enough water to tide over the transition period without any inconvenience to Egypt. In two years the lower dam would be completed from floor level to crest, and then it would be ready to store the five milliards of cubic metres of water for which it was constructed. Great economies would result from the utilisation of the iron work, dressed stone, and other material of the existing dam.

139. **The Wadi Rayan as a Flood Escape.**—We have already considered in paragraph 132 the Wadi Rayan as a reservoir. We now consider it as a flood escape. Working in conjunction with the proposed White Nile Reservoir, whose functions we have explained in paragraph 137, the Wadi Rayan escape could draw off 100,000,000 cubic metres per day for thirty days every high flood, which we may consider as coming once in three years. In other words, the Nile would be relieved for thirty days of 100,000,000 cubic metres per day, or 1200 cubic metres per second. This would lower the level of the Nile half a metre in a high flood. The following table shows that the level of water in the Wadi would under these conditions fluctuate between R.L. 18 and R.L. 12 metres. If this quantity were drawn off for thirty-five days, the level would fluctuate between R.L. 23 and R.L. 18 metres, and if the interval were forty days the level would fluctuate between R.L. 28 and R.L. 22.

While we considered the Wadi as a reservoir, we assumed that the evaporation would be 2·5 metres per annum ; but to be on the safe side for an escape we take the evaporation now as 2 metres per annum : that would mean 6 metres in three years.

A channel capable of discharging 1200 cubic metres per second should be taken from a point about 10 kilometres upstream of Biba, where we have a direct line into the Bahr Bilama depression. The canal would have to be 100 metres wide, run 10 metres deep in flood on a slope of $\frac{1}{20,000}$ in the 14 kilometres in the Nile Valley, and 35 metres wide and 14 metres deep in the hill cutting on a slope of 1 in 10,000. In the Nile

Valley the velocity would be 1·1 metre per second, and in rock 2 metres per second. The estimate would work out as follows:—

Earthwork	14,000,000 at £·05	£700,000
Rock and marl and sand excavation	25,000,000 at £·10	2,500,000
Masonry work	. . . . .	500,000
Land	. . . . .	200,000
		£3,900,000
Contingencies, 15 per cent.	. . . . .	600,000
	Total . .	£4,500,000

Table 244 showing the behaviour of the Wadi Rayan depression used as a flood escape, if there were discharged into it 100,000,000 cubic metres per day (1200 cubic metres per second) for thirty days every third year. If the annual evaporation were taken as 2 metres per annum, the total depth of evaporation in three years would be 6 metres.

TABLE 244.—THE WADI RAYAN AS A FLOOD ESCAPE.

Year.	Quantity discharged, in milliards of cubic metres.	Metres evaporated.	R.L. of Water Surface, in metres.	Contents of Water in the Depression, in milliards of cubic metres.	Remarks.
1	3	– 6	– 12	3	See Table 240, giving contents of Wadi Rayan depression, in paragraph 132.
2 and 3			– 18	1·8	
4	3	– 6	– 4	4·8	
5 and 6			– 10	3·5	
7	3	– 6	+ 1	6·5	
8 and 9			– 5	4·7	
10	3	– 6	+ 5	7·7	
11 and 12			+ 1	5·8	
13	3	– 6	+ 8	8·8	
14 and 15			+ 2	6·8	
16	3	– 6	+ 10	9·8	
17 and 18			+ 4	7·4	
19	3	– 6	+ 12	10·4	
20 and 21			+ 6	8·1	
22	3	– 6	+ 14	11·1	
23 and 24			+ 8	8·9	
25	3	– 6	+ 15	11·9	
26 and 27			+ 9	9·2	
28	3	– 6	+ 16	12·2	
29 and 30			+ 10	9·6	
31	3	– 6	+ 17	12·6	
32 and 33			+ 11	10·0	
34	3	– 6	+ 17·5	13·0	
35 and 36			+ 12	10·5	
37	3		+ 18	13·5	

140. **The Lake Tsana Reservoir.**—Mr C. E. Dupuis made a special study of the value of this reservoir after his visit to the lake in the winter of 1902–03. The rainfall of 1902 had been scanty, so that Mr Dupuis saw the lake at a low level. His calculations occupy the closing paragraphs of *The Basin of the Upper Nile.*

According to Mr Dupuis, the lake surface is 3000 square kilometres, and the catchment area (exclusive of the lake) is 14,000 square kilometres. He takes the rainfall as 1 metre per annum, of which nearly the whole falls in the four months June, July, August, and September. He calculates the run off the catchment which reaches the lake as 25 per cent. of the whole.

He found the Blue Nile at the outlet of the lake discharging 42 cubic metres per second on the 31st January 1903. The minimum level, he was told, would be 50 centimetres lower at the end of May, when he calculated it would be discharging 23 cubic metres per second. The high-water level was reached at the beginning of October, and its water mark was 1 metre higher than the level on the 31st January 1903.

During the thirty-three days he was there the lake fell 15 centimetres with 17 cubic metres per second entering the lake and 40 cubic metres per second leaving it. The difference between the two discharges was 23 cubic metres per second, or 2 millions of cubic metres per day. This in thirty-three days amounted to 66 millions of cubic metres, while a fall of 15 centimetres at the lake represented a loss of water of 450 millions of cubic metres. The difference between the two was 384 millions of cubic metres, or a depth of water over the whole area of the lake of 128 millimetres in thirty-three days, *i.e.* about 4 millimetres per day, which was due entirely to evaporation. He assumed a loss by evaporation of 4 millimetres per day during the eight dry months and 2 per day during the rainy months, or 1·2 metres per annum. These values agree with measurements at Adis Ababa in 1907.

He calculated the water entering the lake per annum as 6572 millions of cubic metres, the water evaporated as 3648, and that discharged by the Blue Nile 2924 millions of cubic metres. Consequently he considered the efficient capacity of the reservoir as 3 milliards of cubic metres in a mean year and probably 2 milliards in a poor year. If by suitable works at the outlet of the lake the whole of the supply could be utilised, he calculated that in a mean year a discharge of 15 million cubic metres per day, or 173 cubic metres per second, could be counted on for the six months between the 1st January and the 30th June. This would mean about 120 cubic metres per second for 180 days in a poor year.

We consider his figures too high. In a year of poor rainfall the total fall might be 90 centimetres, or even less (though we consider the mean

1·1 metres), of which one-sixth, or 15 centimetres, might reach the lake. This would give for the water entering the lake

$$3{,}000{,}000{,}000 \times \cdot 90 = 2{,}700{,}000{,}000 \text{ on the lake area,}$$
$$14{,}000{,}000{,}000 \times \cdot 15 = 2{,}100{,}000{,}000 \text{ from the catchment,}$$
$$\text{or } 4{,}800{,}000{,}000 \text{ cubic metres in all.}$$

The quantity evaporated would be 3,000,000,000 × 1·2, or 3,600,000,000, leaving 1,200,000,000 to be discharged by the river. This would mean a discharge of 12 millions of cubic metres per day for 100 days, or of 140 cubic metres per second for 100 days, of which fully 75 per cent. in this torrential river would reach the Gezira. If we take the duty of water in the Sudan for cotton in summer as 60 cubic metres per acre per day, this water would suffice for the irrigation of $\frac{3}{4} \times \frac{12{,}000{,}000}{60}$ or 150,000 acres of cotton. Even with these low figures it would be wise for the Sudan Government to consider the question of the utilisation of this lake as a reservoir for the Gezira lands.

141. **Summary of Proposals.**—We have shown in paragraph 135 that if the proposed works in the Sudd region answered the purpose for which they were intended, the discharge of the White Nile at Khartoum might be increased from 450 to 600 cubic metres per second, or by 150 cubic metres per second for 100 days, during the summer. This is equivalent to a reservoir capacity of 1,300,000,000 cubic metres at Aswan. The cost of these works can only be guessed, but an expenditure of £2,000,000 cannot be considered as excessive. These works would provide no protection in flood.

In paragraphs 136 and 137 we have stated that the Gebel Auli Reservoir on the lower White Nile could store 2,750,000,000 cubic metres of water at a cost of £800,000, while the Gebelein Reservoir on the upper White Nile could store 2,500,000,000 cubic metres of water at a cost of £600,000. Both these works would materially control the Nile flood and protect Egypt from inundations. Now, if the discharges from these reservoirs were sent down continuously on a very gently falling river, nearly the whole of the water would get to Egypt; while if it were discharged so as to cause the river to rise steadily, the greater part would be wasted in filling the trough of the river. With a wisely conducted discharge we might count on 2,250,000,000 cubic metres reaching Aswan from the Gebel Auli Reservoir and 1,750,000,000 from the Gebelein Reservoir.

In paragraph 138 we have shown how an Aswan reservoir at R.L. 120·00 metres would store 2,600,000,000 additional cubic metres of water. Such a work would cost £4,000,000. It would ordinarily have no effect on the Nile flood; but, at its raised level, it might be used effectively on some great emergency. The silt could be partially scoured out afterwards.

In paragraph 139 we have calculated that a Wadi Rayan escape could

lower the level of a high flood and afford protection to Egypt against an inundation. Such a work would cost £4,500,000.

Now we have calculated in paragraph 134, that if we wish to add 1,000,000 acres to the perennially irrigated area of Upper Egypt, and 600,000 to that of Lower Egypt, we need an additional 2,200,000,000 cubic metres of water at Aswan. This could best be supplied by the Gebel Auli Reservoir at a cost of £800,000.

If we wish to add a further 600,000 acres to the perennially irrigated area of Lower Egypt, we require a further reserve of water of (3,800,000,000 – 2,200,000,000, or) 1,600,000,000 cubic metres. This could best be supplied by the Gebelein Reservoir at a cost of £600,000.

If the 600,000 acres at present under the lakes is to be converted to perennial irrigation, we require an additional reserve of water of 1,700,000,000 cubic metres. This could be supplied either by a raised Aswan dam or by training works in the Sudd region. The first would be a greater certainty than the other. The raised Aswan dam would cost £4,000,000, and the works in the Sudd region possibly £2,000,000.

Since the Gebel Auli and Gebelein Reservoirs protect Egypt from the dangers of an inundation, they should under any conditions be carried out.

If, as we stated in paragraph 138, the land in the Sudan becomes sufficiently valuable to justify the Government of that country in demanding that the valley of the lower White Nile be not sacrificed to Egypt, it will be possible to utilise the Gebel Auli Reservoir for controlling the floods and storing water in September, October, and November, and then letting it come down in December to be stored in the Aswan Reservoir raised to R.L. 120·00 metres.

Should it be found that the shallow White Nile reservoirs, especially the upper one, are wasteful owing to excessive evaporation in the long months of the dry season, they will still be invaluable, as reservoirs, in delaying the clear flood of this branch, and sending it down to Aswan in December, after the muddy water of the Blue Nile and Atbara has passed. All this clear water could then be stored in the Aswan Reservoir raised to R.L. 120·00 metres. In any contemplated project for a raised Aswan dam, it might be advisable to ask the Ambursen Hydraulic Construction Co. of Boston (U.S.A.) for a competing design.

If in the meantime the works in the Sudd region were steadily prosecuted, the Sudan would be enabled to withdraw gradually the whole of the summer supply of the Blue Nile for the irrigation of the Gezira. This supply could be augmented by reservoirs on the Blue Nile and its tributaries, notably at Lake Tsana, as has been explained in paragraph 140. With greatly increased summer supplies the Sudan might even prepare projects for the perennial irrigation of the Dongola Province.

CHAPTER XIII.

THE ASWAN DAM.

142. Preliminary Works of Construction.—143. The Building of the Dam.—144. The Gates.—145. The Subsidiary Lock.—146. The Talus.—147. The Raising of the Dam.—148. Criticism of the Dam.—149. Criticism of the Raised Dam.—150. Summary of the Cost of the Dam.—151. The Working of the Reservoir.—152. Thermal Stresses in the Dam.

IN paragraphs 131, 132, 134, and 138 we have given the history of the dam and described it. We now describe the building of the work and its working.

142. **Preliminary Works of Construction.**—As already stated in paragraph 133, the works were begun in the winter of 1898 and completed by the end of 1902. Plate LXXII. gives the plan and longitudinal section of the dam as proposed to be built. Plate LXXIII. gives the plan made after the work was built. Plate LXXIV. gives the longitudinal and cross sections showing how it was actually built. On the latter are shown in dotted lines the proposed additions to the dam to be dealt with in paragraphs 147 and 149. We now quote from the Report of the late Mr W. J. Wilson, Director-General of Reservoirs, contained in the Irrigation Report for 1899:—

"The most interesting work carried on during the year was the construction of 'sadds' or temporary dams across three out of the five deep channels of the river, which cross the line of the dam and carry the supply of the Nile in the winter and summer. These channels are known as the Bab el Kebir, Bab el Harun, and Bab el Sughair, and the fall through them from about 100 metres above to an equal distance below the axis of the dam was about 3 metres at low Nile. These are the first rapids of the Aswan Cataract, and the total fall in the river from Philæ to Aswan was about 5 metres before the regime of the river was disturbed by the construction of these works.

Before the dam can be built across these channels it is necessary to construct temporary dams up and downstream of the site sufficiently water-tight to allow of the area between them being laid dry by pumping.

These dams are most easily made of bags filled with coarse sand; but before they could be commenced, it was necessary to throw stone 'sadds' across the channels so as to reduce the volume of water flowing down them, and it was found most convenient and economical to make these sadds downstream of the site. They were kept sufficiently far from the foundation pit to allow of sand-bag sadds being made between them and the dam if it was found necessary to do so.

It was decided to make the stone sadds before the flood, so as to allow of the

To face p. 718. Willcocks and Craig Egyptian Irrigation.

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GENERAL PLAN OF ASWAN.

SCALE = $\frac{1}{4,000}$.

NOTE: *Areas hatched are levelled below sluice inverts.*

To face p. 718. Willcocks and Craig Egyptian Irrigation.

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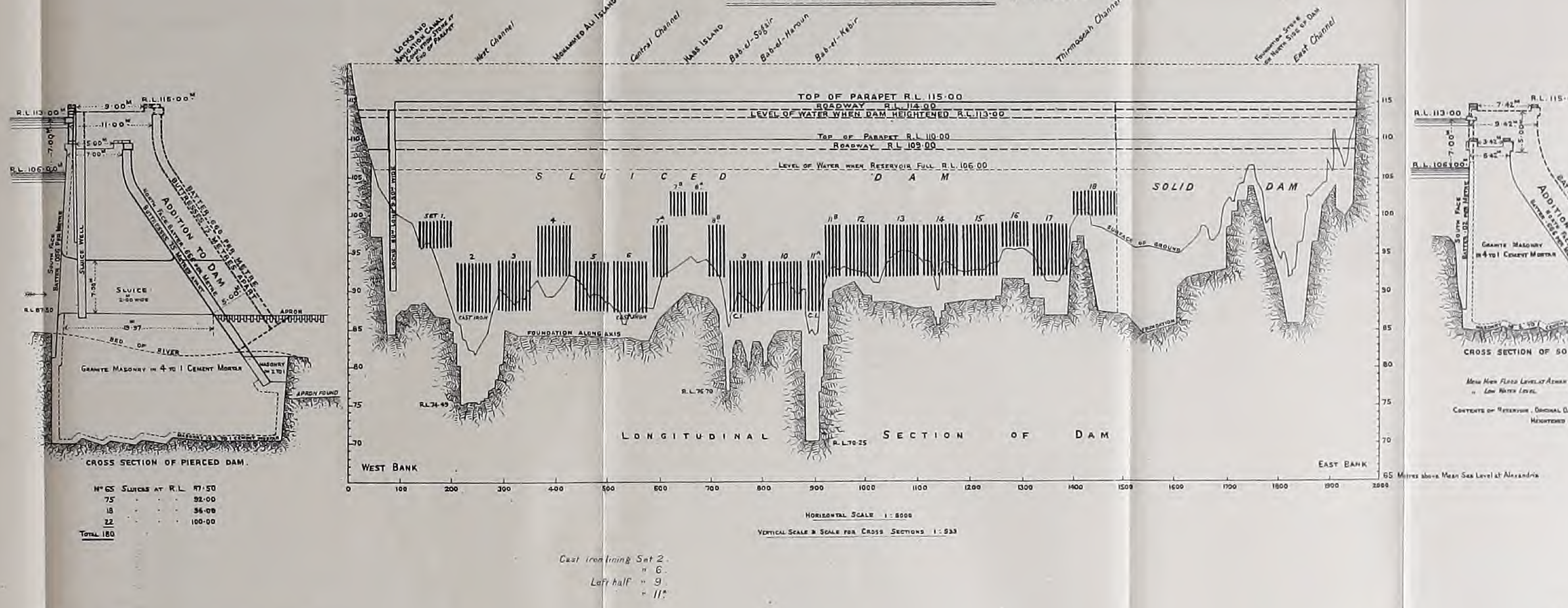
ASWAN RESERVOIR

Heightening of Dam (project)



To face p. 718. Willcocks and Craig Egyptian Irrigation.

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sand-bag sadds being commenced as soon as the flood should subside. In the old condition of the river before the sadds were commenced the mean low water level in the river upstream of the site of the dam was R.L. 90·0 and the mean high flood level was R.L. 98·0. The stone sadds were made up to R.L. 93·0, or 5 metres below ordinary flood level. They were made of large stones weighing from one to four tons with small stones to fill up the spaces between them. Wire nets or 'shimfs,' filled with small stones and weighing from one to four tons were also used, but were not so successful as had been expected, as the wires were frequently cut by the sharp edges of the stones and the stones fell out. The large stones and 'shimfs' were put into place by a crane working on the end of the sadd; the smaller stones were tipped from wagons. Above water level and on the downstream slopes the stones were carefully packed and rails were built into the slopes and crests of the sadds to keep the stones together.

The three channels are close together, and the sadds across them formed practically one continuous sadd. They were constructed from the east side, and the first stone was put into the Bab el Kebir on 13th March. This channel was successfully closed on the 17th May under a head of about 2 metres; before it was closed the current became so strong that stones a couple of tons in weight were frequently carried downstream. The length of this sadd was 60 metres, greatest depth 19 metres, width at top about 9 metres, downstream slope 1 to 1, and upstream slope $\frac{3}{4}$ to 1. The quantity of stone used in it was 15,000 cubic metres. The width at top was sufficient to allow of rails being laid and wagons run to supply materials for the other sadds.

The sadd was then continued across the Bab el Harun, a channel about 50 metres wide, and much shallower than the Bab el Kebir. It was closed without difficulty on 12th June, and, as the current was not strong, comparatively small stones were used in it.

The closing of the Bab el Sughair was then taken in hand. This channel is only 35 metres wide, but it was about 8·5 metres deep throughout. Owing to the discharge down the Bab el Kebir and Bab el Harun having been reduced to the quantity of water leaking through the sadds, and the consequent heading up of the water upstream while the downstream level had been reduced, the rush of water through the Bab el Sughair was very strong, and increased as the channel was narrowed. Stones of three and four tons in weight were carried away, and for some days no progress was visible. On a suggestion of Mr Fitzmaurice, two large railway wagons were loaded with wire nets filled with stones, each net weighing from two to three tons; the nets were then wired together and secured to the wagons by steel ropes passed over the nets and under the wagons, rails were laid to the end of the sadds, and the two wagons, each weighing about twenty-five tons, were run bodily into the cataract. They were heavy enough to stand the force of the water, and formed a toe against which other stones were stopped. The sadd was closed on the 11th July."

We consider that the method adopted for closing the 40-metre wide and 8-metre deep breach in the Hindia dam on the Euphrates was cheaper and more effective. The breach was closed by falling towers. Each tower consisted of five cubes of masonry, 3 metres × 3 metres × 3 metres each, one above the other, through the middles of which was taken a stout wire rope

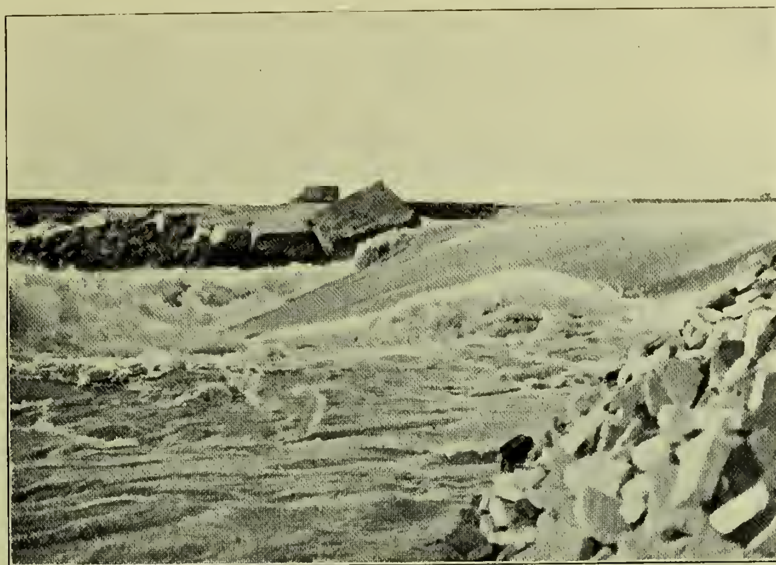
firmly fixed to the dam. Plate LXXV., taken from the *Geographical Journal* for January 1912, shows the method well. The bottom metre of the lowest cube consisted of three pillars each 60 centimetres × 60 centimetres on the side nearest the breach, while the bottom metre farthest from the breach was tapered from 1·50 metres at the top to 75 centimetres at the bottom. Holes were left in the three pillars for inserting tubes of gunpowder. As the gunpowder was lighted, the three pillars collapsed and the tower fell into the breach as shown in the plate. The upper half of Plate LXXVI. shows the method adopted at Aswan, while the lower half shows the excavation of the foundation along the western part of the dam.

143. **The Building of the Dam.**—The Nile looked kindly on the work during the whole time of construction, and gave a number of low floods in which to bring it to a successful termination.

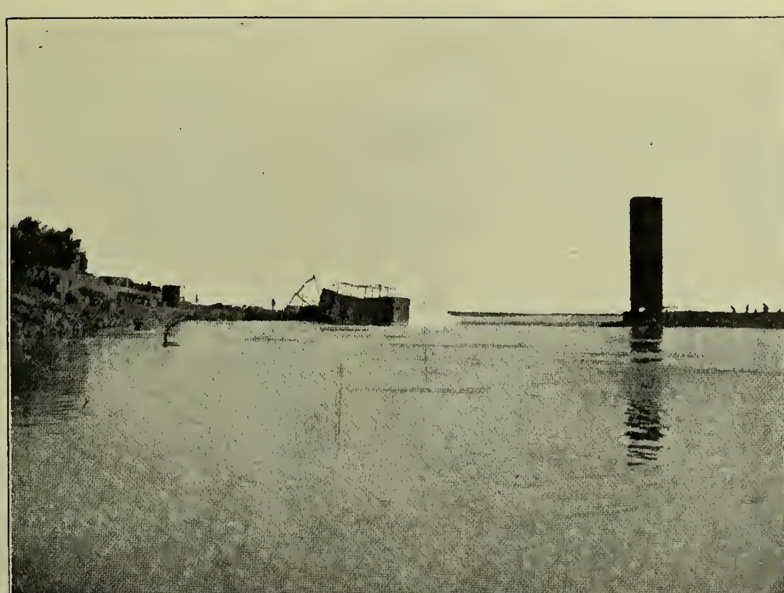
We quote from a paper read before the Institution of Civil Engineers (No. 3361), by Mr (now Sir Maurice) Fitzmaurice, the resident Engineer in charge :—

"The batter on the upstream face is 1 in 18, and on the downstream face 1 in 1½. With the exception of that portion of the foundation masonry which is built hard to the rock at the sides, the facing consists of squared rock-faced granite in courses varying between 12 inches and 24 inches in depth. All the face-work was laid by cranes, and is built on the upstream side in 2-to-1 Portland cement mortar, and on the downstream side, with the exception of the two lower courses, in 4-to-1 cement mortar. The hearting is of granite rubble in 4-to-1 cement mortar, but for 0·67 metre above the bottom, and for a similar distance where built hard to the rock at the sides, it is in 2-to-1 cement mortar. Practically all the stone for the hearting was of such a size as could be laid by hand, and was carried on men's backs from the wagons on to the dam.

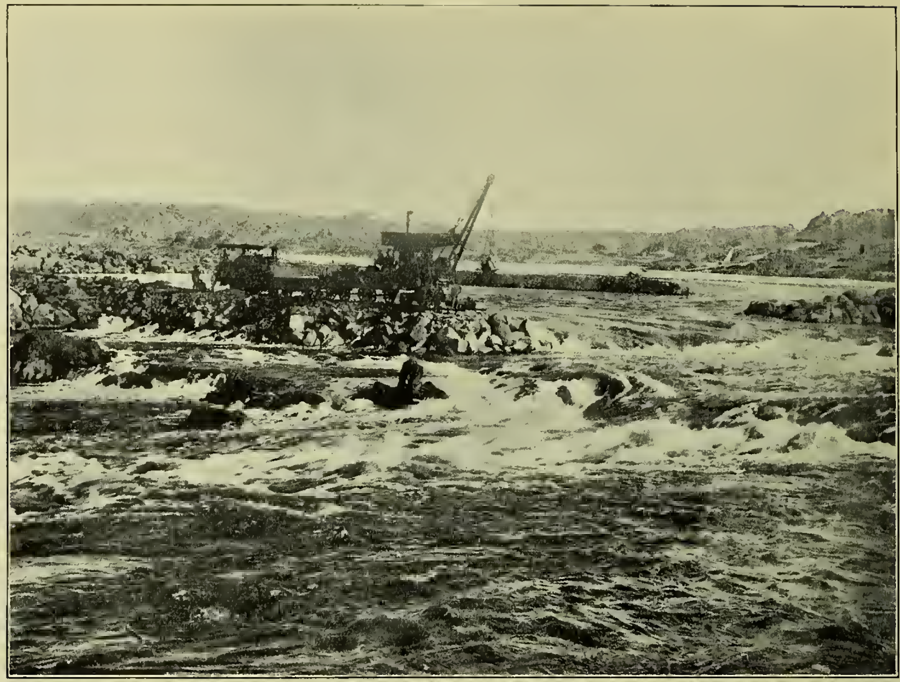
It was originally intended that the hearting should be built in lime and burnt clay, as an abundant supply of both was easily obtainable. About 10,000 cubic metres were actually built with these materials, but the contractors found it impossible to burn the clay and bring it on to the works at such a rate as was required to complete the dam within the contract time. It was therefore determined to use 4-to-1 cement mortar. The results of some tests made with the burnt clay and lime mortar in various proportions are given later, but it may be useful to make a few remarks here on this mortar. The limestone, which was a nearly pure calcium carbonate, was obtained on the river-bank about 70 kilometres below the site of the work, and was boated up to the railway below the cataract and then taken about 12 kilometres by rail to the kilns, where it was broken and burnt with about 2½ cwt. of coal to the ton. The lime was then slacked and screened before being ground in the mills with the burnt clay. The clay was obtained beside the railway, about 9 kilometres from the works, and was made into bricks and burnt in clamps at this place. For burning it required about 1½ cwt. of coal per ton of rough clay, or 1¾ ton per ton of ground clay. When burnt to a bright red colour, it was either ground in a mill or broken by beating it with pieces of wood, and was then screened. In either case the resulting crushed clay had to pass a sieve of 400 meshes per



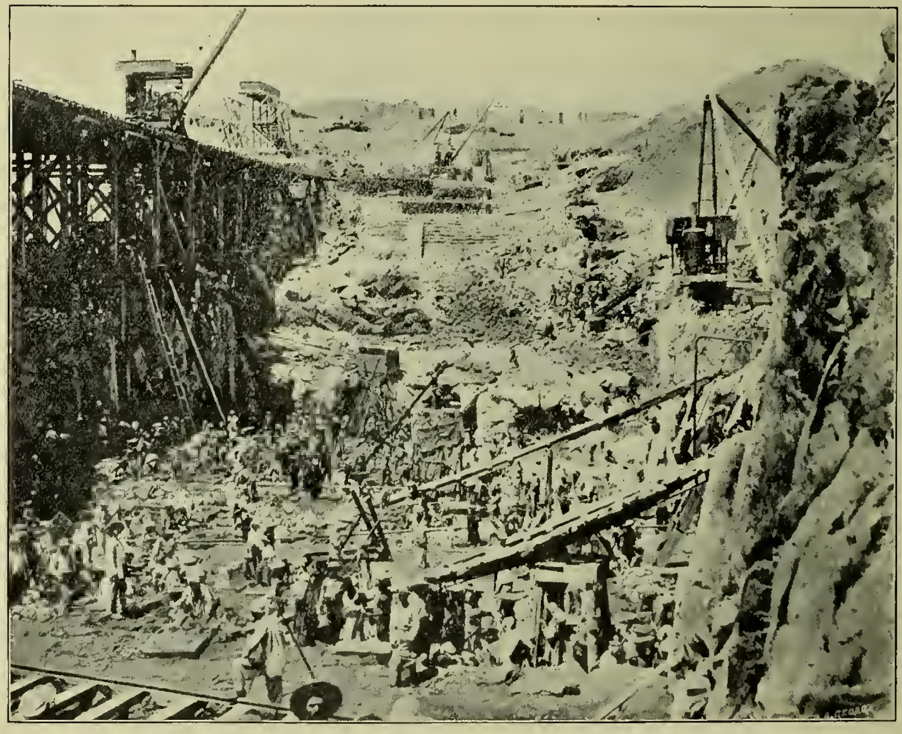
Breach in old Hindia Barrage on the Euphrates (from Downstream).



Closing the old Hindia Barrage Breach (from Upstream).



Closing one of the Channels at Aswan.



Aswan Dam, Excavation of West Channel.

square inch without a residue of more than 8 per cent. The clay and lime, with about 10 per cent. of sand, were ground together in an ordinary mortar-mill until thoroughly mixed. The resulting mortar, when the grinding, screening, and mixing were carefully done, was excellent and much more water-tight than 4-to-1 cement mortar. The average tensile strength after twenty-eight days was 160 lbs. per square inch. The amount of plant, however, required to provide and to bring where needed sufficient mortar to build between 30,000 and 40,000 cubic metres of masonry in a month would be enormous. The lime mortar, too, does not set as quickly as cement mortar, which greatly interferes with the progress of work when large quantities of masonry are being laid, and when it is necessary to run cranes on top of the work. The author is also of opinion that, where all coal has to be imported from England, as is the case in Egypt, there is no saving in cost by using lime mortar. With cement mortar the cement is burnt in England, or some other country where coal is comparatively cheap, and at Aswan there was no difficulty in obtaining excellent sand. With lime mortar the coal for burning both lime and clay and for running crushing- and mortar-mills had to be imported. Where, on the other hand, fuel could be obtained locally, or where a good hydraulic limestone was found, lime mortar would probably be cheaper than cement.

The weight of masonry was taken at 2300 kilograms per cubic metre. The actual proportion of mortar used varied from 35 per cent. to 42 per cent., and the actual weight of the masonry in 4-to-1 cement mortar with 40 per cent. of mortar is 2396 kilograms per cubic metre. The assumed weight of 2300 kilograms per cubic metre is therefore fair, making allowance for the impossibility of being certain that every stone is bedded solid.

The majority of the sluices were lined with granite ashlar of an average thickness of 0·67 metre. The granite sills were alternately through stones and half stones. The former were 2·50 metres long, and therefore extended 0·25 metre under the side walls; the latter had a joint near the centre of the sluice, and extended 0·65 metre under the side walls, and all sills were 0·65 metre deep. The granite lintels were 2·70 metres long, giving a bearing of 0·35 metre on each side wall, and were also 0·65 metre deep. There was a cast-iron domed lintel over the bell-mouth entrance. All ashlar was set in 2-to-1 cement mortar. Thirty of the lowest sluices were lined with cast iron. The rubble around the cast iron was built in 2-to-1 cement mortar for a thickness of 0·65 metre, and the webs of the castings tied the lining well into the masonry. The only reason for the use of cast iron in preference to ashlar was that the iron could be laid much more quickly and the time for working in some of the channels was very short.

In case it should be necessary to repair one of the sluice-gates at any time, owing to its having become jammed, or for any other reason, a shield on the roller shop-blind system was devised, which could be lowered from the roadway of the dam so as to close the upstream side of the sluice. This shield was designed by Sir Benjamin Baker, and the details were worked out and the shields were supplied by Messrs Ransomes & Rapier.

During the season 1899–1900, work was in progress in four out of the five main channels of the river, and by the first week in March excavation was in full swing over this length of the dam, and masonry had been commenced in the Bab el Harun. Over a long length of the excavation, however, the rock was found not to be solid, and in many cases the rotten granite could be excavated with a pick. This was

particularly the case in the Bab el Kebir and Bab el Sughair. By the end of March the excavation in the former channel had been carried down to R.L. 73·00 metres, or 9 metres lower than the level of solid rock shown on the contract-drawings; and at the latter channel the excavation had reached R.L. 79·00 metres, or 4 metres below contract level of rock. The same rotten granite continued during April, and by the end of that month solid rock had not been touched. Only three months now remained before all work for the season would have to be suspended on account of the Nile flood, and before that time the masonry had to be brought up to R.L. 94·00 metres, or the sadds would have to be reconstructed in the following season. It was impossible to allow any doubt about the quality of the foundation, and excavation was carried on with, if possible, increased vigour. During the first week of May the bottom improved, and masonry was commenced on the 10th May in the Bab el Kebir, and on the 26th May in the Bab el Sughair. In the former case the foundation-level was R.L. 70·5, or 11·5 metres below the level of rock shown on the contract-drawings.

When it was considered that sufficiently good rock for foundation had been obtained in any length, the surface was washed and brushed, a careful examination was made, and if thought necessary a drill was put down for 2 or 3 metres to ascertain that there was nothing but solid rock below. As far as possible all blasting was stopped a little above the foundation-level, and all loose or doubtful rock was quarried out by bars and wedges down to that level. Although solid rock was obtained, there were generally a few small springs visible when the surface was cleaned, and although the water came through what in most cases were practically hair cracks in the rocks, the amount of this water, owing to the head under which it came, made it necessary to deal with it very carefully. It had originally been intended to lead all springs through the masonry to the downstream side of the dam; but it was finally considered that, owing to the water coming in in all cases through these fine vertical cracks, generally not more than 1 inch or 2 inches long, only a very small local upward pressure could in the worst case be exerted on the base of the dam, if the springs were carefully grouted with neat cement. In all cases the water from springs was allowed to flow freely until the masonry all round the spring had been built to a considerable height and had set. For this purpose the water from the spring was either carried in a small pipe to a pump, or, if the spring was very small, was baled out by hand. If there happened to be two or three small springs near each other, they were connected by a pipe or a small channel built in the masonry.

Locks were provided for passing ships up and down in the canal. During certain times when the reservoir is full there may be a difference of 20 metres between the water-levels up- and downstream, and a string of four locks situated just downstream of the dam provides for passing the traffic. The total drop from the bottom of the upper canal to the bottom of the lower canal is 7 metres, which is made up by 1 metre between the sills of the first and second locks, and 3 metres between the second and third and between the third and fourth locks. The difference between the surface-level of the two reaches may, however, as above stated, be as much as 20 metres when the reservoir is full; but when the reservoir is emptied, or just before the filling begins, the difference between up- and downstream water-levels may amount to only 1½ metres. The locks therefore have to be worked under a head ranging between 1½ metres and 20 metres.

TABLE 245.—RESULT OF LONG-TIME TESTS OF LIME AND CLAY MORTAR: TENSILE TESTS. (Compare with Appendix II.)

(Clay was medium burnt; lime was newly burnt; sand was screened granite sand.)

Mixture.	Age in Weeks.	Ultimate Tensile Strength in lbs. per square inch.* Individual Tests.	Average.
3 parts by volume clay	13	334, 330, 354, 382	350
2 ,, ,, lime	26	324, 314, 332, 314	321
	52	356, 356, 292, 346	337
2 ,, ,, clay	13	330, 316, 298, 304	312
2 ,, ,, lime	26	358, 324, 294, 354	332
	52	366, 400, 390	385
3 ,, ,, clay	13	248, 248, 246, 238	245
2 ,, ,, lime	26	292, 258, 262, 280	273
1 ,, ,, sand	52	314, 300, 300, 302	304
2 ,, ,, clay	13	304, 310, 302, 316	308
2 ,, ,, lime	26	324, 322, 330, 350	331
1 ,, ,, sand	52	352, 322, 312	330
1 ,, ,, clay	13	260, 268, 236, 220	246
2 ,, ,, lime	26	262, 284, 274, 264	271
2 ,, ,, sand	52	310, 298, 296, 288	298
1 ,, ,, clay	13	216, 170, 250, 238	220
2 ,, ,, lime	26	290, 296, 242	276
1 ,, ,, sand	52	338, 304, 278, 270	297
1 ,, ,, clay	13	240, 198, 242, 216	224
1 ,, ,, lime	26	270, 222, 254, 230	244
1 ,, ,, sand	52	268, 302, 260, 256	271

* To convert to kilograms per square centimetre multiply by 0·07; or, nearly enough, divide by 14.

COMPRESSION TESTS.

—	Age in Months.	Average tons per square foot (?)*
1. Medium burnt clay (3 clay to 2 lime); three 6-inch cubes	7	105·7
2. Underburnt clay (3 clay to 2 lime); two 2-inch cubes	8	154·8
3. Medium burnt clay (3 clay to 2 lime); two 2-inch cubes	8	126·3
4. Overburnt clay (3 clay to 2 lime); two 2-inch cubes	8	137·1
5. General mixed sample of clay (3 clay to 2 lime); two 2-inch cubes	8	151·0

* To convert to kilograms per square centimetre multiply by 1·1.

Notes.—1. All lime and clay passed through a sieve of 529 (23 × 23) meshes to the square inch.

2. Sand passed through sieve of 400 meshes, and retained on one of 900 meshes, to the square inch.

3. Cubes kept for the first seven days under a damp cloth and then for six months in water.

Each lock is 80 metres long and 9½ metres wide at the bottom, which is sufficiently large for the anticipated traffic. The facing masonry of the locks is of a much smaller type than the facing of the dam, and was all laid by hand. The sills, gate-floors, quoins, etc., are, however, of very heavy granite ashlar. Each lock-gate consists of a single leaf and rolls back into a recess in the masonry. The two upper gates are 18 metres deep, and weigh about 105 tons each, exclusive of the bascule, etc. The other gates are 14 metres, 11 metres, and 8 metres deep. The opening and closing of the gates, as well as of the valves in the gates, is done by hydraulic power. A turbine is fixed in the dam to drive pumps supplying pressure-water for this purpose. There is no culvert in the masonry for adjusting the water in the locks, but a large number of sluices is provided in the gates.

A brick culvert is built at a low level behind the lock-walls on each side, so that, should there be any leakage from the reservoir when full, through fissures in the rock to behind the walls, the water may be carried off downstream and not allowed to rise.

As already stated, Sir Benjamin Baker was the Consulting Engineer to the Egyptian Government. The successive Directors-General of Reservoirs were Mr W. J. Wilson and Mr A. L. Webb, MM.Inst. C.E. The author from the beginning of the work in 1898 until December 1901 had charge of it on behalf of the Egyptian Government, and at the latter date was succeeded by Mr C. R. May, M.Inst. C.E., who had previously been principal assistant."

144. **The Gates.**—Figures 177 to 180 give elevations and sections of the gates, and horizontal sections of the gate openings, made from direct measurements of the works in 1904.

The following selections are from paper No. 3393, read before the Institution of Civil Engineers by Mr F. Wilfred S. Stokes, M.Inst. C.E., Managing Director of Messrs Ransomes & Rapier:—

Upper Sluices at R.L. 100 and R.L. 96.

These sluices are for the purpose more particularly of regulating the discharge when the reservoir is full, and have, as their level indicates, only 6 metres of head over the sill. The culverts are 2 metres wide by 3·5 metres high. The entrance to the culvert is bell-mouthed and is roofed over by a casting curved on the dam-face and flat at the place where it joins the sluice-lintel. The grooves, lintel, and sill of the sluice are all of cast iron, arranged with machined faces and put together with turned bolts. The sluice is built up of a steel-plate skin with rolled strengthening girders at the back, framed into cast-iron beams on each side, which form the roller-paths.

Adjustable bars are fitted on each side of the face to reduce the leakage as wear takes place, owing to the cutting action of the silt in the water. An adjustable bar is also fitted on the top of the sluice which shuts down on the lintel at the same moment that the bottom of the skin lands on the sill, and thus makes a water-tight joint.

The rollers are arranged in cradles formed of flat bars, and are hung in position on each side of the gates by steel-wire ropes.

The crab has two speeds of lift, namely, for small adjustments by one man or for quick working by four. An automatic self-sustaining gear is provided, so that

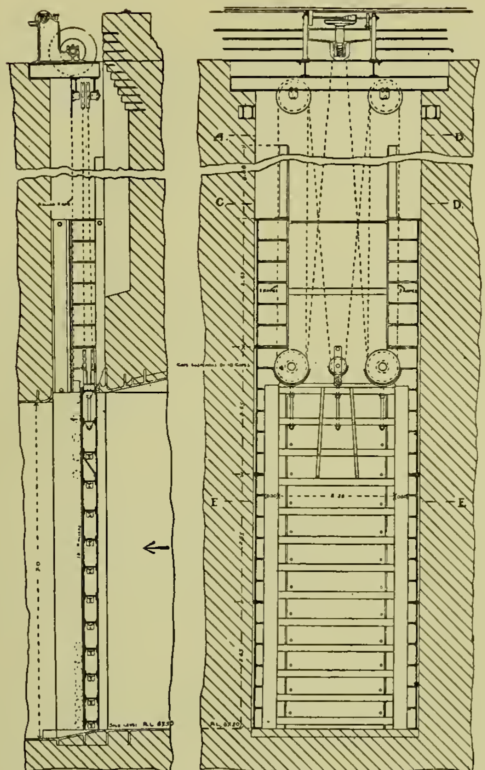


FIG. 177.—Lower Sluice Gate, Aswan. Scale $\frac{1}{150}$.

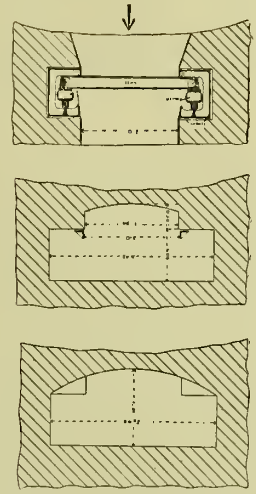


FIG. 178.—Lower Sluice Gate, Aswan. Scale $\frac{1}{150}$.

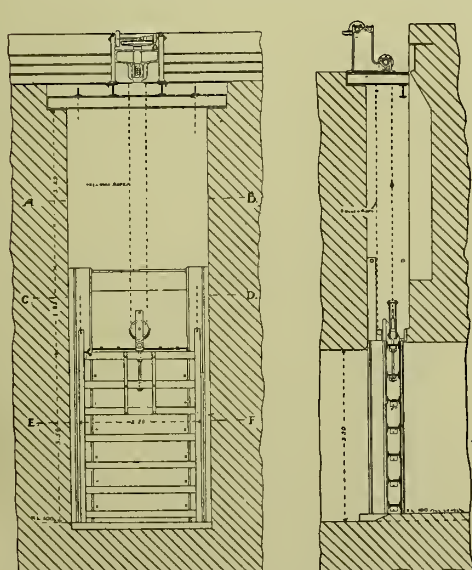


FIG. 179.—Upper Sluice Gate, Aswan. Scale $\frac{1}{150}$.

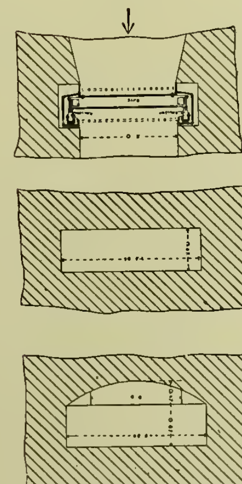


FIG. 180.—Upper Sluice Gate, Aswan. Scale $\frac{1}{150}$.

the sluice (which is not counterbalanced in any way) cannot run down, the handles having to be turned when lowering to release the gear. The barrel-shaft is worked by means of a worm-wheel and worm fitted with a ball thrust-bearing.

All the bearings and pulleys are fitted with screw-down grease-lubricators ; this is the more advisable owing to the sand and dust.

Lower Sluices at R.L. 92.

Sluices without Rollers.—These are 7 metres high by 2 metres wide, and, as has already been mentioned, are simply for the purpose of closing the culverts, and are not to be worked against a head of more than 3·5 metres ; they have, however, to withstand a head of 14 metres over the sill.

The grooves, sill, lintel, and front roof are of cast iron, the gate being formed of wrought-steel joists and plates faced with planed bars bearing against the machined face of the fitted framework.

The sluice is lifted by a six-part steel-wire rope, winding two parts ; the lower pulleys are arranged between plate cheeks attached to the sluices by two pins, which, when withdrawn, allow the rope-gear to be wound up clear of the water during the time the reservoir is full. When it is empty, and the period of high Nile is approaching, the lifting-gear is again lowered and attached, and the sluices are raised as the flood begins.

The crab and platform are similar to those for R.L. 100 and R.L. 96 metres.

Sluices with Rollers.—These sluices are 7 metres high by 2 metres wide, and are for the purpose of regulation when those without rollers are lowered and before the water rises high enough for those at R.L. 96 and R.L. 100 metres to be available.

As the head above sill-level is 14 metres, the rollers and other parts have to be of much more ample proportions and the grooves built into the masonry of considerably larger size than those for the sluices at R.L. 100 and R.L. 96 metres. The high velocity of the water through the culvert has also to be avoided, and hence the rollers are kept well back from the face and an inclined shield-plate is provided to protect them from the direct flow. A whirlpool motion is set up in the grooves, but is not of sufficient force to disturb the rollers hanging below the bottom of the gate when raised.

The grooves are built up of four sections, weighing about 2 tons each. They are bolted together with turned bolts, and are arranged with projections on each side, to key into the masonry and prevent the leakage of water round the back.

The sluice is built up of heavy specially rolled steel joists, with steel skin-plates and cast-iron roller-path girders on each side.

On each side of the face a vertical rod is contained in a groove bolted to the skin. This rod is pressed by the water into the corner formed by the face of the sluice and the face of the fixed frame, and thus makes a water-tight joint ; a horizontal rod fitted in the lintel also serves the same purpose. This provision is not necessary for preventing leakage, but is intended to guard against the cutting away of the faces by the fine matter carried by the water.

It may not be out of place to mention here that Nile water has a peculiar action on paint or other protective coating, and it is quite usual to have to repaint all metal-work that has been under water during each flood, as all traces of paint have, as a rule, been removed by the attrition of the fine silt in the water at high

Nile. All kinds of special paints and varnishes have been tried, but with little success. It is curious that the best standing paint on the sluice work has been the common white-lead letters put on at Ipswich for marking the various parts to assist erection.

The sluice is hung on a ten-part steel-wire rope winding two parts. The crab and pit-covers are similar in design to those for R.L. 87·50 metres.

Lock Gates.

As vessels have to pass through the locks at all states of the water-level in the reservoir, the sill of the upper lock has to be at R.L. 90 metres, *i.e.* 19 metres below the roadway of the dam and quay-level. This necessitated a special design of gate, and for the sake of uniformity all the gates were made alike. There are four locks, each 9·5 metres wide and 80 metres long. The gates are 18 metres, 18 metres, 14 metres, 11 metres, and 8 metres high respectively, the sills being at such a level as to give a drop of about 6 metres between each lock. The great range of water-level prevented their being floated in any way, and they are therefore hung from above upon two sets of free rollers supported upon two bascule girders which span the lock. These girders enable the gate to be moved back into a recess in the side of the lock, after which they are raised so as to allow free passage for vessels.

The 18-metre gate with its carriage weighs 105 tons, and requires a force of about 1 ton to travel it. The gate is formed of fourteen horizontal bow-string girders, spaced so as to be practically equally loaded, bearing against two built-up jamb members faced with greenheart. Cast-iron facings are bolted to the masonry for these to bear against when the gate is closed. The skin is formed of steel plates stiffened by vertical bulb tees. Twelve sluice-openings, arranged in four groups, are formed in the skin for filling the locks, the water from one lock passing to the next, there being no culvert-sluices.

Although the locks are of equal length—namely, 80 metres—the system of passing water from one lock to the next is open to the objection that if successive boats are passed in different directions the upper locks became unduly empty. It is thus necessary to make the normal state of each lock full, so as to be ready for passing in either direction.

The gates are made strong enough to withstand the full head that can come upon them with the downstream side dry. In the case of the largest gates this pressure amounts to 1568 tons; under normal working, however, the pressure is only 1407 tons.

The gate is hung by fourteen sling-rods, placed in pairs, so as to accommodate the altered position of the centre of gravity as the water-level varies, and thus maintain the gate in its true vertical position. The sling rods are so placed on the carriage as to keep the gate clear of its seatings until acted on by reducing the water-level slightly.

The carriage is built up of two roller-path members and seven cross girders carrying the sling-rods. The rollers are in frames, hinged at a point near the bascule girder pivot, so as to allow the bascule to rise. A timber platform covers the carriage and gives access to the gear.

The bascule girders are of fish-belly box section, arranged with the tail end between two fixed girders carrying the roller-path. Cast-iron counterweights are provided to balance the bascule girders, which are framed together at the outer ends

so as to work together. They rest when in position on bed plates on each side of the lock, a toggle-gear being provided to raise the tail end off the pivot on which it turns.

It was decided to insert a small turbine in a chamber in the dam, to work hydraulic pumps of 20 cubic feet per hour capacity, and to actuate the gates by hydraulic power.

The pressure-water at 750 lbs. per square inch is carried along the dam, and across the lock in duplicate copper pipes to two accumulators of 16 cubic feet capacity. Two accumulators were adopted so as to reduce the height of the house, and also to have one always available in case of repairs. Their capacity is equal to two complete operations of one gate. An automatic valve is arranged to stop the turbine when both accumulators are fully raised. Auxiliary steam-pumps are also provided in the accumulator house, in case the turbine should break down.

The face-valves of the lock-gates are worked by four direct-acting rams with pistons, arranged to give the return stroke when pressure is taken off the top side. Four valves, not hitherto mentioned, are provided at the bottom of the gate to induce scour and to remove silt from the neighbourhood of the gate. These valves are also worked by direct-acting rams of similar design.

The above hydraulic cylinders are carried upon an extension of the gate taken up through the carriage above the platforms. These extensions also convey the power required for travelling direct to the gate, and thus relieve the sling rods from side strain.

The travelling motion is worked by two hydraulic rams on the carriage with multiplying steel-wire ropes. These ropes actuate a shaft having on each end a barrel, on which are wound two ropes, one end of which is fastened to the fixed work at each end of the travel of the gate. Thus, if pressure is admitted to one of the rams, the travelling rope on each side is hauled in and the gate is moved, while, when the other ram is worked, the gate travels in the opposite direction.

The bascule girders are each worked by a pair of rams, carried on the fixed girders, acting at the opposite ends of a lever keyed on the pivot on which the girders turn. A small double-acting ram works a toggle for raising the tail end of the girders, so as to give a proper bearing on each side of the lock, and also prevent the tail being depressed by the first rollers which carry the load on to the bascule as the gate travels out.

The valves for working are of the piston type with leathers. Those for the sluices and for the travelling motion are placed on the gate platform, water being conveyed to them by a walking pipe.

The bascule and toggle-valves are on the abutment. An automatic cut-off is fitted to the travelling and bascule motions, and a buffer faced with hemp rope is fixed on to the gate to bring it to rest in its proper position when across the lock.

Messrs Sir John Aird & Co. were the contractors for the construction of the dam. They were represented by Mr John A. C. Blue.

Messrs Ransomes & Rapier were the contractors for the ironwork. They were represented by Mr E. H. Tabor.

145. **Subsidiary Lock.**—A subsidiary lock was built at the low rapid

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downstream of the dam, to aid navigation in winter and summer. The following quotation is from the Irrigation Report for 1903 by Sir Arthur Webb. It describes the building very summarily. Unfortunately no quantities and rates are given, but the work has the reputation of having been built cheaply. The masonry is reputed to have cost under £1 per cubic metre.

"In order to improve the navigation in the river between the Aswan dam and Aswan town, it was decided at the end of 1902 to construct a new lock at the Sahel rapid, where boats experienced great difficulty in passing. The work was put into adjudication and entrusted to Messrs Williamson and Urquhart, who successfully completed the work in one season, so that the ironwork was all fixed to enable the lock to be worked in July 1903. The ironwork was supplied by Messrs Ransomes & Rapier, and is of their usual excellent quality and workmanship.

The total cost of the lock was £49,331."

146. **The Talus.**—The following quotation is from the Irrigation Report for 1906, and is written by Mr M. MacDonald, C.M.G., Director-General of Reservoirs. It gives an account of the talus constructed downstream of the dam (see Plate LXXVII.). The work is sound and good, but if it had been put in hand immediately after the flood of 1903 and pushed with as much energy as it was in 1905 and 1906, it would have been less extensive. However, there is always some soul of goodness in things evil, and in its present heavy form it forms a better toe to the raised dam than it otherwise would have done. The work cost £282,700, but unfortunately no rates are given.

"When the pumping was completed it was found that, as occurred under all other sets of sluices, very considerable erosion had taken place.

As in the preceding season, the talus formation consisted of filling all depressions with rubble masonry, and continuing building right up to within 15 centimetres of the sill level of the sluices, from which point a suitable gradient was given to the surface to allow it to join the natural rock level downstream. The masonry consisted of sound granite rubble set in 4-to-1 cement mortar, except where the talus was more than 3 metres thick, when the proportion of sand to cement in the mortar for the portion below that depth was 6 to 1. In no case, however, was 6 to 1 used within 7 metres of the dam. The facework consisted of fine-grained granite blocks 40 centimetres deep, with every fourth course a heading course of 80 centimetres deep for 30 metres width under the 87·50 sluices—the remaining width being 40-centimetre stones alone without headers. Under the 92 level auxiliary sluices, the apron was made 30 metres in width, the inner 15 metres being laid with 40 centimetres deep squared stones, the outer 15 metres being laid with selected rubble averaging 35 centimetres deep. All face-work was laid in 2-to-1 cement mortar. Work continued up to the 20th July, when the last stone was laid, thus completing a continuous talus, of a width varying between 30 and 60 metres, as was considered necessary, underneath all the sluices and for the whole width of the river, except where the cistern principle of protection was adopted under the 100·00 R.L. sluices at the centre of the dam.

TABLE 246.—QUANTITY OF TALUS WORK DONE IN 1904–1906.

Description.	Quantity.				
	1903–04.	1905.	1906.	Total.	
Sadds . . . cubic metres	...	14,650	22,803	37,453	
Steam pumping in 12-inch pump . . . days	...	440	380	820	
Hand pumping for un-watering and sundry items other than steam pumping, actual cost £		2,454	3,000	5,454	
	cubic metres	cubic metres	cubic metres	cubic metres	cubic metres
Soft excavation	19,754	51,500	46,400	117,654	282,589
Rock ,, ...	3,735	101,000	60,200	164,935	
Rock filling West Bank . .	14,953	22,400	19,399	56,752	
Rubble masonry in 4 to 1 . .	8,222	88,800	33,800	130,822	136,022
Rubble masonry in 6 to 1 . .	...	...	5,200	5,200	
	square metres	square metres	square metres	square metres	square metres
Facework in 2 to 1 . . .	3,080	26,760	22,100	51,940	61,140
Facework in 3 to 1 . . .	...	...	9,200	9,200	
Pointing and sundries, etc. . .	...	5,000	3,292	8,292	
Pitching, West Bank . . .	736	274	3,455	4,465	,,

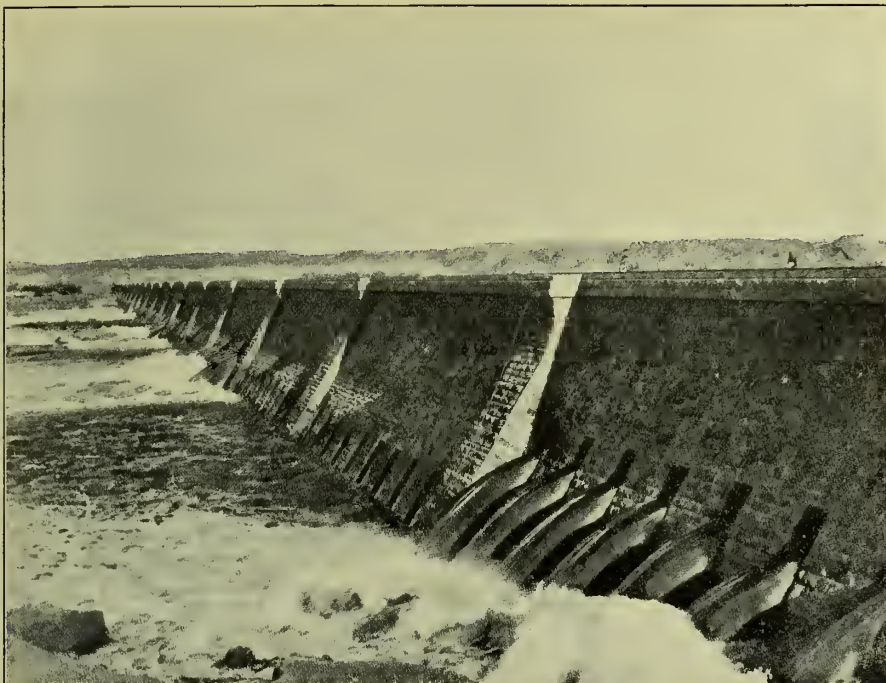
Plate LXXVIII. shows the action of the water downstream of the dam before and after the construction of the talus.

147. **Raising the Dam to R.L. 113·00 metres.**—The following extracts are from the Reports for 1907, 1908, 1909, and 1910, written by Mr MacDonald. They describe the raising of the dam on designs prepared by Sir Benjamin Baker, K.C.B., so that the water surface might be raised from R.L. 106·00 to R.L. 113·00 metres:—

Plate LXXIX. gives photographs of the raised dam.

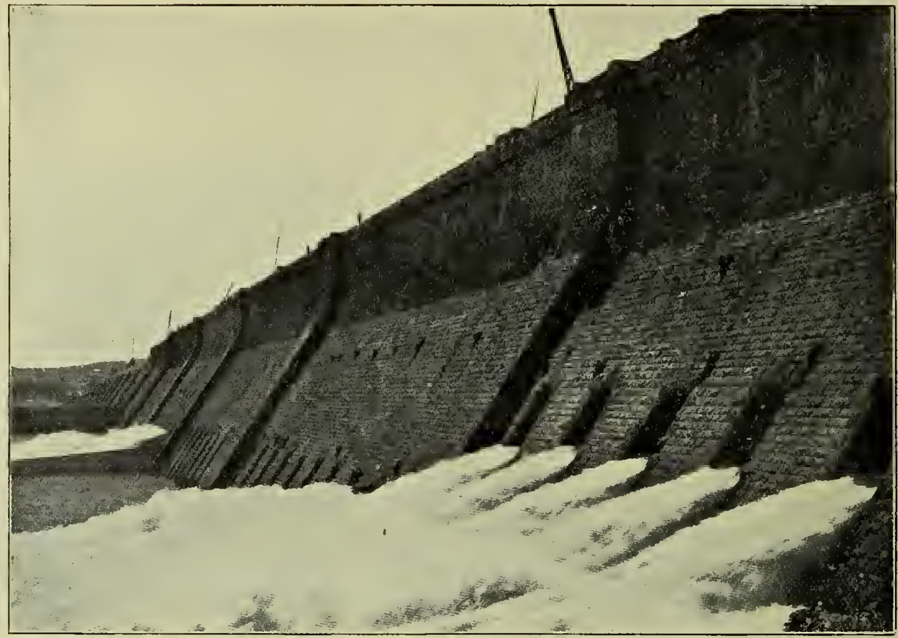
1907.—"Sir Benjamin Baker visited the dam in January, and after making an inspection of the talus works, he advised that the heightening of the dam might be proceeded with in the following manner: the project to consist of building a buttress wall 5 metres thick, having as good a foundation as that possessed by the original dam, in contiguity to the present structure, and downstream of it; and increasing the height of the dam masonry by 5 metres.

As the present dam has cooled internally to a condition approximating to a fixed temperature, and as the new buttress wall will be built on the average at the temperature prevailing during the summer months, it had been decided not to bond the two buildings together, as such bonding would fail when the new wall was in process of cooling to the internal condition of the old building. Sir Benjamin Baker suggested that the best method of arranging for this would be to leave a space between the two walls of from 2 to 6 inches (5 to 15 centimetres) wide: the space to be grouted up when there is no further relative temperature movement;

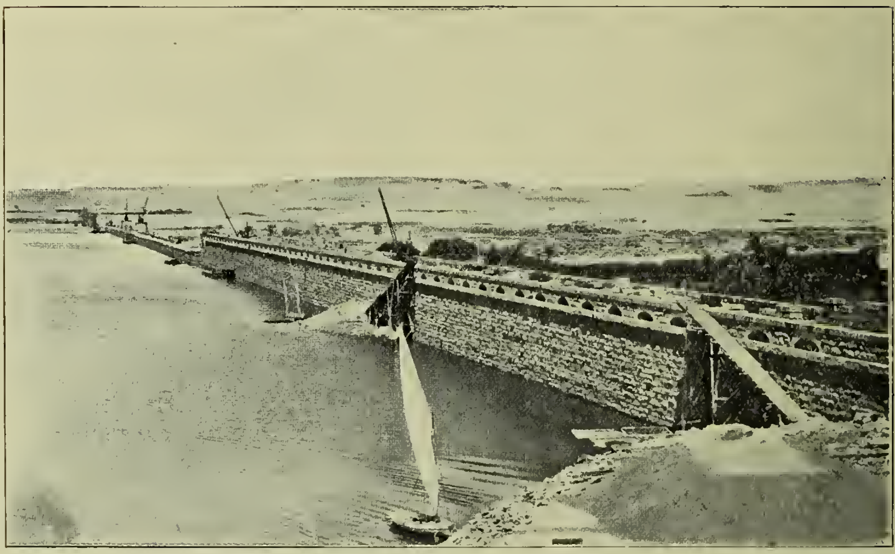


The Aswan Dam before the Construction of the Talus.

The Aswan Dam after the Construction of the Talus.



Raised Aswan Dam (looking east).



Raised Aswan Dam (looking west).

this, it has been decided, will take place after two years. The space will be filled as erection proceeds with clean quarry chips in order to decrease the amount of grout required.

During this period of two years, in order to support the new wall, bearing rods 8 feet long will be placed about one-half their length in both structures. These rods will freely yield to temperature movement while transmitting pressure.

In order to make the grouting practically possible, the space between the walls will be divided into sections not exceeding 14 metres in length, and extending for the whole height of the present dam; the divisions being separated by a projecting line of ashlar stones built into the new wall and abutting on a dressed strip, 8 inches wide, on the old building, and with a red-lead joint between them. In each grouting bay there will be two 2½-inch grouting pipes suitably perforated for distributing the grout. On top of both the old and the new building, after grouting, 5 metres of new masonry will be built.

The present freeboard for wave action of 3 metres has been found to be unnecessary.* The new dam will therefore be 1 metre only higher than the level of the water: thus permitting of the impounding of 7 metres more water for the 5 metres of building.

The sluices will be extended in granite ashlar, even in those cases where cast iron was originally used. In order to avoid a difficult joint at the junction of the new and old work, the new sluices will be 15 centimetres wider on each side: being 2·30 metres instead of 2 metres. As this alteration would make lintel stones unwieldy, ashlar arches will be substituted for them.

The ashlar of the sluices abutting on the original ashlar will have a red-lead joint, with an indiarubber ring 1 inch thick between them.

The sluice ashlar will be built square to the batter of the wall. The low freeboard of the new dam makes it advisable to provide a spillway against excessive storage of water. It has therefore been decided to open arches on the upstream side of the dam into the sluice walls of the one hundred and thirty roller sluices. As these sluice gates are staunched against the upstream face, water passing from the reservoir through these arches will fall downstream of the gates and pass into the river through the sluices.†

The alterations to the locks will consist of building a new lock downstream of the present lowest lock, and thickening and heightening the other lock walls. Two new gates will be erected in the top lock, and the existing gates of the top lock will be removed down to the next lock, and so on. The present fifth lock gate will not be required. The new lock will be at such a height —R.L. 96·00—that the flood will not overtop it, as happens with the existing lowest lock."

Messrs Sir John Aird & Co., represented by Mr H. MacClure, were the contractors for the raising of the dam, as they had been for its building. The ironwork was also supplied by Messrs Ransomes & Rapier for both works.

1908.—"The excavation of the triangular-shaped trench forming the foot of the new wall was thus done wholly in the dry; the only retardation to rapid progress

* This 3-metre additional height was really meant to allow of the reservoir level being raised by 2 metres after the first few years' trial if Philæ allowed of it.—AUTHORS.

† Since applied to the whole length of the dam.—AUTHORS.

was the restriction imposed on the contractors regarding the quantity of dynamite to be used in each hole.

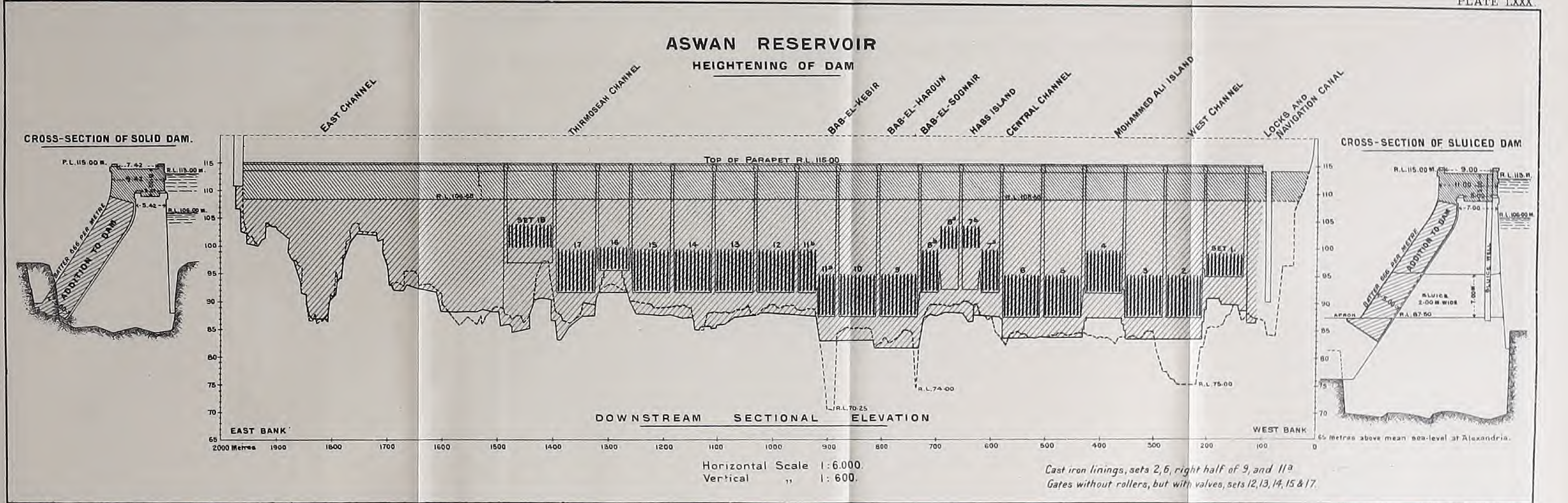
With the exception of the greater portion of set 2, the trench excavation exposed the foundation of the original dam, and it is to be recorded that while slight leakages of water came in places through vertical fissures in the rock itself (which might easily have had their origin from the downstream water), none was traceable as being due to leakage between the original dam and its foundation, although the reservoir was at its full height of 106·00 R.L.

With the commencement of the masonry the practical problem of how to ensure the keeping free of the 6-inch space from spent mortar, sand, and other debris became urgent. The system finally adopted was to bring up first a portion of the wall next the space, about 60 centimetres wide, horizontally bedded with the stones next the space overhanging each other: the cement for the beds and joints being kept back about 10 centimetres from the outer edge: the height brought up at a time was about 60 centimetres. As soon as a short length of building was completed, the loose rubble, composed of hand-washed granite cubes, capable of passing through a 3-inch ring, was laid in position, and covered with folded strips of sacking to fit the space. On top of this again a wide web of sacking was unrolled—one portion being held up against the face of the old dam, and the other lying on top of the sacking which is always laid on newly finished masonry to keep it damp. The whole of the remainder of the building was of course built square to the face of the buttress wall. Building at such an unaccustomed angle—it is 34° off the horizontal—meant that the masons were not able to lay the 3 to 3½ cubic metres per day which they might be expected to do in ordinary horizontal mass masonry. They, however, exceeded the estimate made originally of 2 cubic metres, and were able to build an average throughout the year of 2·26 cubic metres per man per day.

When erosion had taken place below the dam, holes were formed well clear of it opposite set No. 1, but at the time the apron was formed over the area which included these holes it was found impracticable to clean them out and refill with solid masonry. This apron was constructed in 1903, and had a minimum thickness of masonry everywhere of 3 metres. As far as stability as an apron was concerned, it served its purpose perfectly, especially after its rubble face had been removed by subsequent erosion and replaced by squared work similar to that in all the other aprons. When adding the buttress wall to the dam these pot holes, being in too close proximity to the new wall, were cleaned down to solid rock: the method adopted being the sinking of two shafts through the apron over the larger hole, and tunnelling to the others and refilling with masonry: a total of 1035 cubic metres was built in and the whole completed by 25th July."

1909.—"In this middle section of the dam, excavation for the footing of the buttress wall was generally carried deeper than the foundation of the original dam, with the exception of the short lengths marking the sites of the old Bab el Kebir and Bab el Sughair. In these two cases the apron masonry was of great thickness, rendering it a quite suitable foundation for the new work, the only requirement being that a 'V'-shaped trench be sunk into it."

1910.—"The present year was occupied with thickening and heightening the locks. See figs. 181, 182, and 183.



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Aswan Dam Heightening. Cross Section. Scale $\frac{1}{600}$.

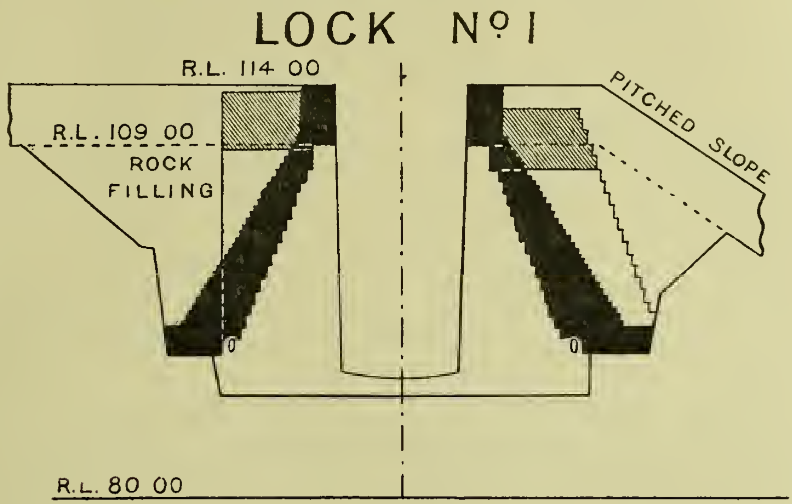


FIG. 181.

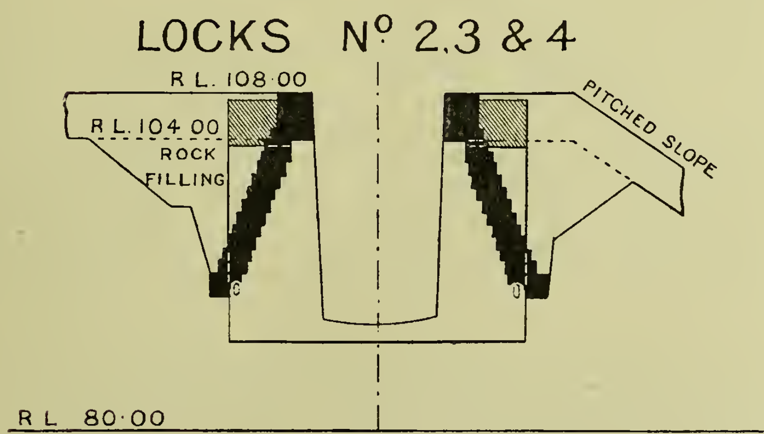


FIG. 182.

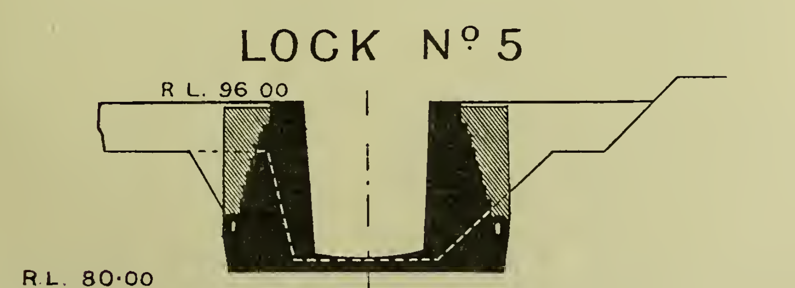


FIG. 183.

The general design for the scheme for altering the locks to make them fit in with the heightened dam consisted of thickening and heightening the lock walls in a somewhat similar manner to that adopted when dealing with the dam, and re-arranging the position of the existing lock gates, and providing new ones where required.

In regard to the thickening, an important variation between its method of construction and that followed in the case of the dam, is that there was no space left between it and the original structure, as the stresses on the two buildings are of a different nature.

The amount of head hitherto put on each lock gate, when working under reservoir-full conditions in the spring and early summer, being as large as was desirable for each of them to carry, the utilisation of these gates in the new scheme entailed construction of a new lock; for reasons of economy this was put downstream at the end of the fourth lock.

The addition of a new lock to an existing series means the addition of one new gate; but as the existing fifth gate would be, under the higher level conditions of the new lock, too low to be of use, the scheme involved the addition of two new gates; and as two new gates would, in any case, have to be supplied for the upper lock—which, of course, was to be heightened 5 metres above the existing level—it entailed the removal of the four available gates from their existing positions to new ones lower down.

By the end of December a considerable quantity of masonry was built behind locks 2 and 3. On the last day of December lock gate No. 5 was removed from its recess and successfully re-erected upstream of lock gate No. 1, right in the mouth of the southern entrance to the locks. This gate, which was handled in two portions, each weighing something over 18 tons, stands a little over 8 metres high; and has, aided by the addition of one or two timber baulks on top of it, been sufficiently high to dam back the autumn flood from access to the locks, thus allowing gates Nos. 1 and 2 to be removed to their new positions in recesses Nos. 3 and 4, and the new gates built in place of them.

If this fifth gate was not so used, a most expensive sadd would have to be made in the mouth of the locks. In comparison with the probable cost of the sadd, the cost of moving the lock gate has been a trifle.

It has been so arranged that the gate will remain available in future to perform the same sadding operation when annually painting the lock gates.

The removal of the gates to the second recess from that in which each of them was standing involved a transference over 160 metres; each lock being 80 metres long. As the smallest of the gates thus handled weighed over 60 tons, and was transported bodily and in its upright positions, great caution had to be exercised during the operations. The procedure adopted was as follows: The gate was first partially dismantled of its carriage and the frames which carry the foot and face valves. The suspension rods were then removed one by one, and new special ball-bearing washer rods substituted. The gate was afterwards lifted by means of these rods to the required height above the floor level; two pivot castings with a cup and ball centre were fixed to the underside of the bottom girder about a metre from each other. The horizontal girders were blocked apart so as to distribute the weight of the gate over more than the bottom girder. The gate was then gradually

lowered off the suspension rods on to two special bogies running on rails—the track of the eastern bogie being curved. The bogie on the curved rails was then pushed forward on its track by crowbars, and the bogie at the other end of the gate similarly assisted on its straight track. To retain the gate in an upright position, the frames which carried face and foot valve cylinders were replaced and tackle secured to them. The result of this travel on the part of the gate on its bogies was to turn it round at right angles to its former direction, and leave it standing in the middle of the lock. While in this position a single straight rail track was laid underneath the gate on which the bogies could travel and be moved along the lock to the new position. Considerable difficulty was met in each case when the gate came to a drop sill. When this happened the railway was carried forward on piles of specially sawn sleepers until the gate stood wholly clear of the sill. The sleepers were then removed, and the railway with its load lowered on to the bottom of the next lock. When the 160 metres were traversed the operation of turning was again gone through, and the gate safely housed in its new position. It has been extremely fortunate that the original construction of the lock permitted the gates to be turned round. It was intended at one time to take the gates to pieces and rebuild them; this must have proved very much more expensive than the scheme adopted.

During the reservoir-full conditions the two upper gates remained closed; the reservoir head being divided between them. This allowed work north of them to be taken in hand as the downstream water level fell.

Masonry building was carried on practically continuously throughout the year, as soon as foundations were prepared for it.

The original design of chase stones for separating the dam into compartments for grouting purposes had to be augmented by the sinking of shafts at several points in the new dam alongside some of the chases in order to make certain that grout could not travel into any adjacent bay. The shafts were successfully sunk during the year, and by the middle of November grouting operations were taken in hand at the east end of the solid portion of the dam, which had by that time been fully two years completed."

The final quotation is from the Report for 1911 and is written by Mr A. MacCorquodale, the Resident Engineer:—

"As already observed in the preceding Annual Reports, the work of thickening and heightening the dam has been carried out very closely in accordance with the programme laid down in 1907, when the work was commenced. The programme was as follows: years 1908 and 1909 to be occupied with the thickening of the dam; 1910, thickening and heightening of the locks; 1911 and 1912, heightening of the dam.

In 1911 (after the 15 centimetres space between the face of the existing dam and the addition to it was filled with cement grout from the foundation up to R.L. 108·20, extending from the west end to 624 linear metres, and from 1497 linear metres to the east end respectively), masonry building was commenced in heightening the dam along these two sections, leaving the central section of 873 metres long to be undertaken in the next, or 1912 season.

Grouting.—Last season's grouting operations have been executed very thoroughly, as has been proved by inspection.

Along the last section to be completed, grouting was started on 30th October and terminated on 20th December, which completed the grouting of the space in the dam.

The tabulated comparative statement subtended shows the grouting done in 1910–1911, and in 1912:—

TABLE 247.—GROUTING BETWEEN OLD DAM AND NEW WORK.

	Grouting began and ended.	No. of Working Days.	Area grouted.	Quantity of Cement disposed of.	Tons per sq. m. Space grouted.	Sq. m. at Space grouted per Ton.	Average Tonnage per Day.	Maximum Tonnage per Day.
		days	sq. m.	tons	tons	sq. m.	tons	tons
First season. Solid Dam. 1487 to 1950 L.M.	1910 Nov. 21 Dec. 31	23	6,349	1175·6	0·185	5·400	51·11	108
Pierced Dam 101 to 624 L.M.	1911 Jan. 7 Feb. 6	28	10,492	2018·9	0·192	5·197	72·10	152
Second season. Pierced Dam. 634 to 1497 L.M.	Oct. 30 Dec. 20	41	17,652	3253·9	0·184	5·425	79·30	145·9
		92	34,493	6448·4	0·186	5·349	70·09	

Inspection Shafts.—All the shafts which were excavated down to foundation level in order to make certain that grout could not travel into any adjacent bay, have been refilled with masonry.

Relief Channel, North of Set 17.—On 23rd March the contractors began to excavate a relief channel, 3 metres wide, extending northwards to drain the water from set 17, so that in future the apron there may be easily examined without recourse to pumping. The channel was completed in the middle of June.

Approach Road, East End of Dam.—The approach road at the east end of the dam has been raised, and a covering of decomposed granite spread over the surface.

Ironwork Contract.—During the year Messrs Ransomes & Rapier have been engaged upon the following works: removing sluice crabs and joists in the sluice wells, sets Nos. 1 to 7B inclusive, and stacking same at lock No. 3, and again erecting them after that particular portion of the dam was heightened; transporting material for and erecting swing-bridge across the lock; cutting by means of the Oxy-acetylene process the old projecting joists in the south face of the dam, and placing in position new joists at a higher level; altering and re-erecting 25-ton crane; dismantling the easternmost 25-ton crane; and conveying and putting in position the portable 50-ton gate in the south entrance of lock No. 1 for scouring out silt which deposits yearly in the canal.

Division Walls.—The series of division walls, north of the dam, for diverting the water from the east to the west channels and *vice versa,* for the inspection of aprons, are now complete.

TABLE 248.—QUANTITY OF WORK IN RAISING THE ASWAN DAM (to end of 1911).

Description.		Total Quantity to December 1911.	Percentage of Schedule Quantity completed.
Dam.			
Excavation, soft and rock, including that in aprons	cubic metres	112,708	per cent. 97
Rubble built	,,	238,959	70
Sluice ashlar built	,,	17,413	100
North face-work built	square metres	36,772	74
Holes for steel bearing rods . . .	No.	35,944	100
Steel bearing rods in masonry . . .	tons	544	100
Cement in grouting space . . .	,,	6,449	154
Locks, including North and South Canals.			
Excavation, soft and rock . . .	cubic metres	107,555	161
Rubble masonry	,,	62,010	95
Rock and soft filling	,,	209,492	100
Ashlar	,,	776	111
Pitching slopes	,,	17,913	90

TABLE 249.—COST OF RAISING THE ASWAN DAM.

Total original estimate of all sums to be expended for heightening reservoir		£1,500,000
Deduct allowance made for land purchase . .	£200,000	
Deduct allowance made for Nubian Antiquarian Research	120,000	
		320,000
Balance, being estimate of cost of heightening dam and locks		1,180,000
Expended on permanent works and supervision (1907–1911) .		1,043,071
Balance to be expended in 1912		£136,929"

Paper No. 4054 on *The Aswan Dam: Protection of the downstream rock surface*, and *thickening and heightening*, was read by Mr MacDonald at a meeting of the Institution of Civil Engineers in April. It has not yet been published by the Institution.

148. **Criticism of the Dam.**—The alignment of the dam had originally been proposed on long sweeping curves following the example of the Betwa dam in India. The International Commission changed this into one continuous straight line. This decision tied down the engineers to a line chosen necessarily by soundings in the river before the river-bed had

been laid dry. The original proposal allowed of more play and choice of alignment and was better than the one actually adopted. At the Betwa dam it was possible to follow the soundest rock on bold curves, and there was a combination of strength and economy which were absent at Aswan.

In addition to this, if the dam had been built on curves, and it had been decided to raise it well above its present level, it would only have been necessary to strengthen the abutments, and the arches would have taken the pressure. This has been pointed out by Mr J. S. Beresford.

In the original design, as in the built dam, there were 140 under-sluices and 40 upper sluices. In the original design, however, 130 of these under-sluices had their floors at R.L. 92·00 metres, while 10 of them were at R.L. 84·00. The 10 sluices at R.L. 84·00 were left as low as possible to allow of the dam being designed with as wide a section as possible in anticipation of its future raising. They were never intended to be built lower than R.L. 92·00 metres, though it was contemplated that a few very low level openings left temporarily in the dam during the first year of construction might be of use if we had heavy summer supplies to contend with. In the dam as constructed, 65 of the under-sluices are at R.L. 87·50 metres and 75 only at R.L 92·00 metres. This is unfortunate. The R. L 87·50-metre sluices are all in the deep section of the river where the mass of the water flows in flood, while the others are in the places where the water approaches with difficulty. If there were going to be a change, exactly the opposite should have been done. The R.L 87·50-metre sluices do three times their share of the work, and the others one-third. The action is aggravated by the fact that the fifty gates without rollers, which are always the first to be lowered, have had to be placed in the higher sluices. The bottom metre of each of the fifty gates without rollers has been provided with a valve opening. Small roller gates act as valves, and are operated at all levels of the reservoir.

In connection with this subject we should like to note that the amount of water discharged through each opening in the dam depends not only on the depth of water on the floor but also on the rate at which the water can approach the sluices. At the Betwa dam, which is submerged in flood and divided into two by a high island, the channel to the left is 230 metres wide, with a mean depth of 15 metres in full flood and a section of 3400 square metres. The right channel has a width of 700 metres, a mean depth of 8 metres, and a section of 6000 square metres. The left-hand channel carries 42 per cent. of the discharge of a high flood and passes it over 230 metres in length of the dam, while the right-hand channel carries 58 per cent. of the discharge and passes it over 820 metres in length of the dam. Each metre in length of the left dam is two and a half times as effective as a metre on the right dam. The water cannot get at the right-

hand dam. Now at the Betwa, advantage might be taken of this fact to raise the reservoir level by 3·50 metres, by raising the right-hand dam permanently by 2·50 metres with 1-metre high drop gates over it, and then lowering the left-hand dam by 1 metre and providing it with 4½-metre high drop shutters as at Suresnes or Poses on the Seine. Such a modification of the work would not affect the height of a very heavy flood.

This varying discharge of approach on to different points of weirs, dams, and regulators is at the bottom of many of the discrepancies between observed constants. It certainly very seriously affects the constants at the Aswan dam, for in ordinary and low floods the discharge of approach along much of the dam is very low, and the openings cannot pass the water which never reaches them. They are credited with having certain depths of water on their sills, but on many of their sills there might almost be sand. If all the under-sluices had been at one level, this great discrepancy might not have existed between the actual head we see and the theoretical head. At the Assiut weir, where the openings are at one level, the sandy bed of the river upstream of the weir undulates greatly, well above the floor level of the weir, and consequently, while the water in flood is tossing over the gates and seemingly everywhere equally energetic and equally full of vigour, the silt is being deposited on the downstream floor just under the waterfall at one place, while not far off the pitching is settling down into scoured-out holes. The velocity of approach does not differ much; it is the discharge of approach which differs.

In the original design it was intended to protect the rock on the downstream side of the dam from the action of the falling water by the creation of a cushion formed by a low subsidiary weir. This would not have been sufficient, and the magnificent talus masonry as constructed is a vast improvement.

In the dam as built there is another improvement on the design. The final downstream ashlar blocks at the under-sluices were designed with their beds horizontal; they were built with their beds at right angles to the downstream batter. The improvement was due to Mr M. MacDonald, then Sir Maurice Fitzmaurice's assistant.

The dam was specified to be built with undressed stone on its downstream face, laid in coarse cement mortar joints at right angles to the downstream batter. The interior stones were to have been laid in jagged layers, roughly parallel to each other, and all at right angles to the downstream face, as one of us had built the Betwa dam. The thickness of the joints in the body of the dam was to have been the same as on the face. As actually built, the downstream face stones are of roughly dressed granite, laid at right angles to the batter; but the interior masonry is of very much smaller rubble, undressed, and laid in horizontal layers. This

is inferior to the original specification. There is no bond whatever between the face stones and the interior stones. Mr MacDonald would prefer to lay every stone – face and interior alike—in roughly horizontal layers, as he considered it difficult to ensure mortar filling the interstices between stones lying on a slope. However the stones were laid, the face and interior stones should be of one kind, all coarse-jointed or all fine-jointed.

The dam as designed was to have had all its under-sluices lined with granite. In order to expedite the building, thirty were lined with iron. These thirty openings would have been better if lined with granite, as the iron and masonry have never been happy together. In the widened portion no iron has been allowed anywhere, though the fact that the width of openings was increased by 30 centimetres would have made it very convenient to employ iron.

Some 200 metres in length of the right flank of the dam were generally founded on very poor rock, and the excavation here was carried down deep and the dam provided with numerous weepers. This was sound engineering. In this length a stout earthen bank should be thrown up on the upstream side of the dam, and, if it were laid out as a garden, it would be no disfigurement to the work. If done with skill, it might even add to the appearance.

The work was designed to be in keeping with the buildings of Upper Egypt, whose architecture lends itself well to massive and continuous walls, and its bold pylon cornice would have added height and majesty to the dam. This pylon cornice was displaced by a rugged projection covered with a retreating capstone, which gives the work an unfinished appearance and deprives it of many metres in height as seen from the downstream side.

149. **Criticism of the Raised Dam.** — The Aswan dam, as has been already pointed out, was designed so that it might have the water surface of the reservoir it created raised from R.L. 106·00 metres to R.L. 112·00 metres, or by 6 metres, without adding in width to the base of the structure. One extra metre was allowed for safety, so that theoretically the dam was capable of holding up water to R.L. 113·00 metres. It would have been economical and easy to have raised the level to R.L. 112·00 metres. If R.L. 112·00 metres were considered too much, the dam might have been raised to R.L. 111·00 metres.

Once it was decided to go outside the base and add to the width of the foundation of the dam, the whole question of the Egyptian and Sudan requirements should have been thrashed out, and then it would have been found that the true solution was to raise the dam to R.L. 118·00 metres, as originally planned, and impound 4 milliards of cubic metres of water; or even to raise to R.L. 120·00 metres and impound 5 milliards.

To stop at R.L. 113·00 and impound less than 2½ milliards was short-sighted.

It would have been sound engineering to have utilised all we have learnt from the dam, and to have built downstream of the splendid talus a new work capable of holding up 5 milliards of cubic metres of water, or twice what the raised dam can do to-day. This would have been no disparagement of the work, for imitation is the sincerest flattery. The talus of the old work, with the foundation of the old dam upstream of it, would have provided a splendid apron for the new work, protecting it from springs.

Adding to the downstream side of the old dam an additional horizontal width of 6·5 metres was against the canons of sound engineering. As very important principles are involved in this addition of new masonry to the downstream face of the old dam, we shall devote some space to their examination. *All these criticisms will apply to the design of the dam and the principles of design. They will have nothing whatever to do with the work of construction.* The following is epitomised from *The White Nile and the Cotton Crop, I.*, page 701 :—

"The additional width of base of 6·5 metres will be built, not invariably on a foundation designed and prepared for supporting a massive wall subjected to an ever-varying pressure, but often on the apron designed and constructed for ensuring a safe flow of water along its surface. This patchwork addition of heterogeneous masonry will be tied by countless iron bars to the downstream face of the main dam; and if the new work settles anywhere, as it may do, it is within the range of probability that it may tear off the facework of the dam, which facework, as built, is itself heterogeneous with the interior masonry of the dam. Now, in masonry dams subjected to the greatly varying strains of the rising and falling waters of the reservoirs they form, the homogeneity of the structures is essential to their stability and their long life."

If a dam is raised in masses of masonry which are roughly horizontal, it is more or less a monolith. The raised dam, however, has been built in vertical masses cemented together; and before they were cemented together the upstream part had been already subjected to water pressure while the downstream had not. Now, when such a heterogeneous mass of stuff with vertical joints is suddenly subjected to heavy water pressure, and the downstream side receives far severer pressure than the upstream side, if the foundation rock is inferior, there is bound to be a settlement of the downstream vertical mass: and if the settlement be ever so slight, the weak vertical joints will yield. This has happened over some 200 metres of the dam—not uniformly, of course, because the rock is not uniform, but more where the rock has been very inferior and less where the rock has been less so.

The vertical masses which had been built independently of each other were cemented, and then in the first half of 1912 the dam was subjected to

the pressure of the low level reservoir. Mild cracks and fissures occurred in the new work. The joints were raked out, the water allowed to trickle down inside the raked-out joints, and then covered over with false pointing. In the latter half of 1912 the dam was subjected rather abruptly to the pressure of the high level reservoir, and then the joints opened out again far more seriously this time, and the new work separated from the old. As the old dam in this reach was provided with weepers and was itself founded in places on rock which was like coarse sand,

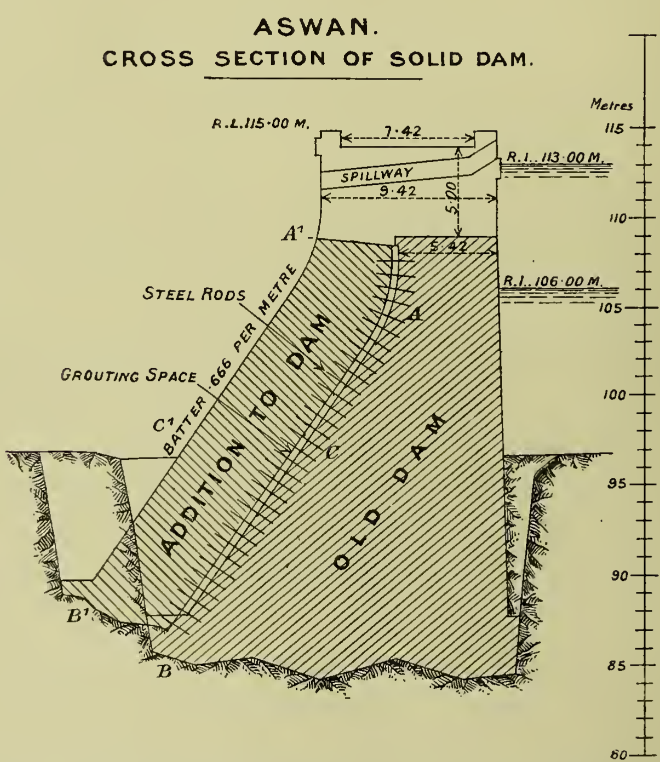


FIG. 184.—The addition has settled. Springs work up from B to A through the rock where it is very inferior, or through the weepers, and ooze out from C' to A' above ground level.

serious leaks showed themselves on the downstream face of the new work.

Fortunately for the stability of the dam the old work is well able to hold its own without any additions, and is doing so. Where the new work has settled, it has been greatly improved in appearance on its downstream face by the joints being raked out and false-pointed. The leaks are concealed from view and led off to low ground on the downstream side. The position is as shown in the section. The old dam is doing all the work, and the new addition is acting here and there as a buttress where it

has not settled. The highest pressure is at the toe of the old dam B, and B′ is relieved of water pressure. There is no reason why B B′ should settle any further. By its dead weight leaning against the old dam it aids it to that extent, though it is not itself strained as an integral part of the dam.

Mr J. S. Beresford has suggested that the downstream batter A C B should have been cut into well-marked horizontal steps to take the weight of the new work. This might have prevented slip, but the principle of adding to the downstream face at all is not sound. A greatly raised new dam would have been the true solution.

The following selections from a letter by Mr Alessandrini in *The Engineer* of 11th July 1913 (to which one of us replied on 18th July) give an account of the leakage through the dam :—

"The 1200 metres of sluiced dam is dry, not because the water there cannot travel through the walls, but because it is trapped by the sluice wells on the upside of the dam, down which it drops into the sluices themselves, and cannot show on the surface of the work. The proof is that where the gates in the sluices without rollers are staunched on the downstream side of the wells, and the wells are consequently full of water, the filtering water passes through just as freely as it does on the solid dam. There, the wells are not open and are not acting as drains, as in the gates with rollers, where the outside face of the dam is consequently dry."

"French engineers understand this point very well, as they are now building a dam where they are making a whole series of vertical arches on the upstream side, similar to the sluice wells at Aswan, in order to trap the leakage water and prevent it travelling through and showing on the outside of their dam. These arches lead to trenches which deliver the water on the outside at the bottom of the dam. What the French engineers are making now on the upstream of their dam, the Aswan engineers made on the downstream side; they made some of the filtering water run in small channels cut in the face of the dam, and this for the sake of appearance."

Mr Alessandrini has asked why there is no longitudinal fissure between the old and new dam along the roadway. There was a roughly horizontal fissure high up the wall at about the height of the point A′ on the downstream face. If the whole of the top of the dam from side to side above the level of the old roadway had not been new work, and the new and old work had met in the roadway, the fissure would certainly have been along the roadway. It was the homogeneous cap of masonry from side to side at the top, supported at intervals as stated at the bottom of page 742, which transferred the fissure to A′ (fig. 184).

Speaking in a general way, one might say that where the additional work is built on inferior rock it adds little strength to the dam, and where it is built on sound rock it adds unnecessary strength.

150. **Summary of the Cost of the Dam.**—We now give a completion report of the original dam.

TABLE 250.—ORIGINAL ESTIMATE OF THE DAM.

Excavation—187,000 cubic metres at £·20	£37,500
Coffer-dams and pumping	80,000
Rubble masonry—321,000 cubic metres at £1·00	321,000
Granite ashlar— 27,000 „ „ 7·00	189,000
Sandstone ashlar— 25,000 „ „ 3·00	75,000
Brickwork— 26,000 „ „ 1·80	49,500
Regulating apparatus and lock gates—3,000 square metres at £75	225,000
Contingencies and land	248,000
Total	£1,225,000

TABLE 251.—COST OF THE DAM WITH ACTUAL QUANTITIES AND RATES OF ORIGINAL ESTIMATE.

Excavation— 774,540 cubic metres at £·20	£154,900
Rubble masonry—496,340 „ „ 1·00	496,400
Brickwork— 6,820 „ „ 1·80	12,300
Ashlar— 41,400 „ „ 7·00	289,800
Banks— 100,000 „ „ ·20	20,000
Gates—3,000 square metres at £75·00	225,000
Cast-iron linings for 30 openings	45,000
Contingencies and land	248,000
Total	£1,491,400

TABLE 252.—COST OF THE DAM AND RATES PAID TO CONTRACTORS.

Excavation— 774,540 cubic metres at £·30	£238,900
Rubble masonry—496,340 „ „ 2·30	1,135,900
Brickwork— 6,820 „ „ 2·80	19,540
Ashlar— 41,400 „ „ 8·20	342,600
Banks— 100,000 „ „ ·25	25,400
Gates—3,000 square metres at £112·00	337,900
Cast-iron linings for 30 openings and contingencies and land	340,000
Total	£2,440,240

If the dam could have been built by departmental agency, in the way in which such works are built in India, it would have been built for £1,500,000—especially as the floods during the time of construction were extraordinarily low or very moderate ; but under the political conditions which prevailed in 1898, all risks for accidents by flood and field had to be taken by the contractors. Moreover, the work was hurried and the excellent and abundant lime mortar of the country changed for cement

mortar. Excavation had been allowed for at £·20 per cubic metre for the whole of the stuff to be stripped off. If this had been done departmentally, the estimate would have automatically allowed for bad rock. If, for example, the rock had been all as sound as our borings and the surface led us to believe, the quantities and rates would have sufficed. If unsound, as they only too often proved to be below the surface, the quantities would have increased and the rates decreased; but with a cast-iron contract it was different, and the excessive cost of the excavation and the difficulty of adjustment were unavoidable. The excavation taken sheer down as shown in the lower half of Plate LXXV. exceeded the original estimate by 487,000 cubic metres for an excess of masonry of 144,000 cubic metres. This meant a great amount of very inferior stuff somewhere else, which by departmental agency would have been done very cheaply indeed. Such works are better done by departmental agency where the Government engineers are tied down to nothing. The estimate of the regulating and lock gates was approved by Mr F. D. M. Stoney himself, and under ordinary conditions would not have been exceeded. But, as already stated, the work was built by the contractors taking upon themselves the risks of five floods, which might have been as extraordinarily high as they were low.

The talus cost £283,000. Raising the reservoir level to R.L. 113·00 in the manner in which it was raised cost £1,500,000. The whole dam has cost therefore £4,220,000, thus made up—

Reservoir to R.L. 106·00 metres	£2,440,000
Talus	280,000
Reservoir raised to R.L. 113·00 metres . . .	1,180,000
Land compensation, etc.	320,000
Total . .	£4,220,000

If the work could have been done by the Department itself, and the Government engineers taken all responsibilities on themselves, while the talus works had been hurried on after the first flood, the dam would have cost as follows:—

Reservoir to R.L. 106·00 metres	£1,500,000
Talus	200,000
Reservoir raised to R.L. 112·00 metres . . .	500,000
Land compensation, etc.	320,000
Total . .	£2,520,000

151. **The Working of the Reservoir.**—We have already given in paragraph 27, Table 126, the contents of the Aswan Reservoir, which we repeat here:—

Water Level R.L.			
120·00	5000 million cubic metres (if raised)		
118·00	4000	,,	,, (if raised)
115·00	3000	,,	,,
113·00	2425	,,	,,
112·00	2150	,,	,,
110·00	1700	,,	,,
105·00	825	,,	,,
100·00	300	,,	,,
99·00	225	,,	,,
98·00	165	,,	,,
97·00	110	,,	,,
96·00	75	,,	,,
95·00	40	,,	,,
94·00	24	,,	,,

The following table gives the dates of discharge of the reservoir from 1903 to 1912:—

TABLE 253.—DATES OF DISCHARGE OF THE ASWAN RESERVOIR.

"Statement showing dates and levels on which the supply from the reservoir began and its emptying ended, since the regulation was instituted. (Actual regulation commenced on 20th October 1902.)

Year.	Supply begun on	Readings.		Emptying ended on	Readings.		Period of Regulation (days).
		Reservoir.	Aswan Gauge.		Reservoir.	Aswan Gauge.	
1903	March 10	106·00	85·03	June 25	94·43	86·12	107
1904	May 10	106·09	84·86	30	91·56	86·07	52
1905	1	106·04	84·40	July 18	93·20	85·75	79
1906	11	106·01	84·65	21	94·22	86·19	71
1907	April 4	106·40	84·94	August 1	94·50	88·02	120
1908	March 29	106·20	84·65	July 17	93·02	85·97	111
1909	April 18	106·03	85·10	3	93·61	86·91	77
1910	May 2	106·11	84·90	17	89·63	85·69	77
1911	April 30	106·15	85·00	21	95·45	86·40	83
1912	5	107·12	84·90	14	94·97	85·65	101 "

We now give the report of Mr D. A. F. Watts, Director of Works, on the working of the reservoir during 1911.

"*Filling of Reservoir.*—The annual filling of the reservoir was commenced on 6th February, when the gauge at Aswan recorded a level of R.L. 86·76 and the reservoir gauge R.L. 97·57.

The filling was postponed beyond the recognised dates and levels of previous years at which operations are begun, when Aswan gauge records a level in the vicinity of R.L. 88·00.

This was occasioned by the work in connection with the heightening of the dam, it being imperative that the grouting operations, then in progress, should be completed before any very great head of water was put into the reservoir so as to cause more leakage through the sluice gates than could be coped with conveniently.

R.L. 106·00, or full reservoir, was attained on 5th April, varying volumes of from 3 to 30 million cubic metres per day being abstracted from the normal river over the period.

Emptying the Reservoir.—The principle adopted since the reservoir was first used was to divide the supply into two portions: the first being used to produce a constant level at Aswan thoughout part of April, May, and part of June; the discharge of the second half being so distributed between June and July as to accelerate the early part of the flood.

In continuation of the above principle, a programme of emptying was prepared on 5th April, proposing a constant level at Aswan of R.L. 84·95 when the falling river normally reached that level, some time about the end of April. This programme was approved and sanctioned.

The river during April fell steadily, but rather slower than was anticipated, Khartoum gauge showing very little movement; and it was deemed safe on these conditions to suggest a level for the first period—throughout May—of 5 centimetres higher, or R.L. 85·00.

On 30th April Aswan gauge recorded R.L. 85·00, and for fifteen days thereafter this level was maintained by the help of the Reservoir.

On 1st May Roseires gauge gave indications of a sharp rise. The rise continued and culminated on 19th May, the gauge on that date standing over 2 metres higher than at the beginning of the month.

When making up a preliminary programme of emptying, factors such as this cannot be taken into account, and show how very impossible it is to estimate with any degree of accuracy what level can be maintained at Aswan for the first period.

Aswan gauge was raised 10 centimetres, or to R.L. 85·10, on the 15th May; to R.L. 85·20 on the 20th May; to R.L. 85·30 on the 25th May; and to R.L. 85·40 on the 30th May; thus the level of Aswan at the end of May was 40 centimetres higher than the level suggested in the amended programme submitted at the end of April.

Roseires gauge fell away from the 19th May, dropping 1½ metres before again starting to rise permanently on 2nd June.

The periods of 'lifts' in Aswan gauge were lengthened in duration and the regulation was concluded on 21st July with Aswan gauge standing at R.L. 86·40.

The volumes added to the river varied from 3 to 19 millions of cubic metres daily and represent a percentage of from 6½ per cent. to 46½ per cent. of the total volume passing Aswan, the total contents of reservoir being 941,190,000 cubic metres.

[Table

TABLE 254.—REGULATION OF ASWAN RESERVOIR—EMPTYING, 1911.

Date.	Days in Period.	Mean Normal Aswan Levels. R.L.	Mean Actual Aswan Levels. R.L.	Volume, cubic metres per second, in Normal River.	Volume, cubic metres per second, added to River.	Total Volume, cubic metres, River with Reservoir.	Volume added to River in millions of cubic metres per day.	Volume added to River in millions of cubic metres during each Period.
					per cent.			
April 30 to May 15	15	84·93	85·01	496	32 = 6·5	528	2·79	41·89
May 15 to May 20	5	84·88	85·10	476	91 = 19·1	567	7·88	39·39
May 20 to May 25	5	84·86	85·21	468	147 = 31·4	615	12·74	63·71
May 25 to May 30	5	84·81	85·31	451	209 = 46·3	660	18·07	90·34
May 30 to June 4	5	84·92	85·41	491	215 = 43·7	706	18·52	92·62
June 4 to June 11	7	85·20	85·51	610	143 = 23·4	753	12·36	86·56
June 11 to June 17	6	85·51	85·61	752	49 = 6·5	801	4·20	25·23
June 17 to June 24	7	85·37	85·71	687	164 = 23·8	851	14·15	99·05
June 24 to July 9	15	85·40	85·80	703	193 = 27·4	896	16·64	249·56
July 9 to July 12	3	85·85	86·19	921	180 = 19·5	1101	15·51	46·55
July 12 to July 21	9	86·15	86·39	1078	137 = 12·7	1215	11·81	106·29
Total volume supplied from Reservoir								941·19

ANNUAL COST OF MAINTENANCE.

Salary of Accountant	£262	
Permanent establishment	318	
Permanent engineer	300	
		£880
Agents *hors cadres*	4,035	
Travelling allowance and telegrams	560	
Furniture and instruments	50	
Temporary staff	3,420	
Dredging	3,900	
Maintenance and repairs	7,200	
Maintenance and repairs (second estimate)	913	
Post expenses	52	
Office stationery	100	
		20,230
Maintenance of Island	170	
Maintenance Reservoir gardens	90	
		260
Total		£21,370"

It will have been noticed that Mr Watts in his report on the working of the reservoir says that, as in previous years, the supply was divided into two portions: the first was used to keep a constant level through part of April, May, and part of June, and the other half to accelerate the early part

of the flood. On page 412 are given quotations from the Irrigation Reports confirming this and showing how the whole of this half was practically lost to Egypt. Fig. 185 shows this waste very clearly. Between the 25th May and the 15th July the river downstream of Aswan rose from R.L. 85·00 to R.L. 86·00. From Table 131 it will be seen that at these levels the mean width of water surface of the Nile from Aswan to Cairo is about 450 metres and the distance 900 kilometres, and a rise of the river by one metre means the sacrifice of 400,000,000 cubic metres to fill the trough of the Nile before the water can enter the canals. In other words, two-fifths of the whole of the reservoir water was used to raise the level of the Nile. This water

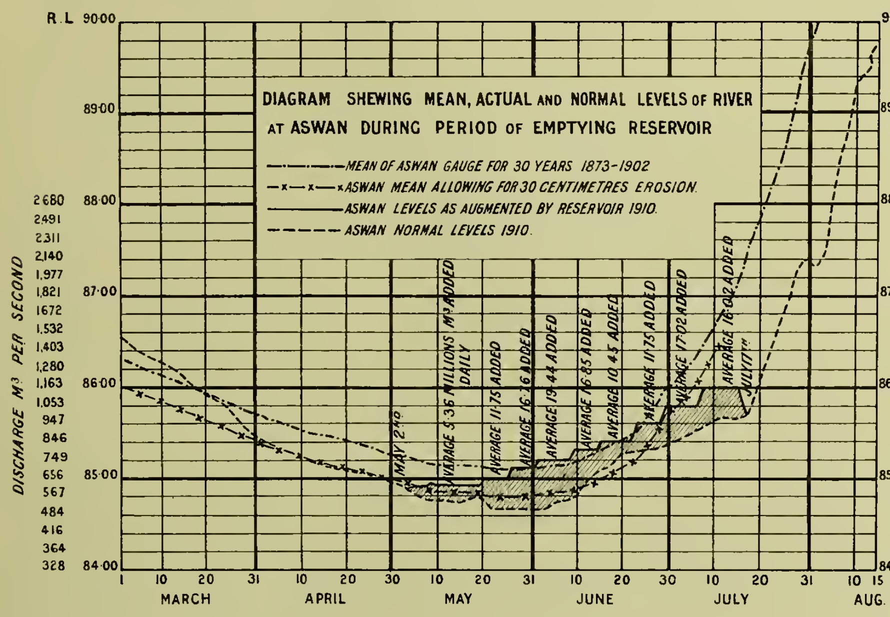


FIG. 185.

helped neither the cotton crop nor the rice crop. This has been repeated every year. Where then, it may be asked, did the water come from which enabled the cotton area to be so greatly increased as it has been since 1903? The real answer came as a great surprise to us.

At the same time that the Aswan Reservoir was completed, another important work was carried out. The sudds were removed from the channel of the Albert Nile in the Sudd region. It will be seen from Table 137 (page 253), page 268, page 405, and paragraphs 134 and 135, that, owing to the removal of the sudds, the discharge reaching Wadi Halfa in summer has been increased by nearly 200 cubic metres per second. It is this increase which has come on to Egypt. And in addition to it has been the increase of the seepage water entering the Nile owing to the conversion of 400,000 acres of the Middle Egypt basins to perennial irrigation. Mr

Langley, in the Irrigation Report for 1911, has some very interesting figures on this head.

"Three discharges were taken in the river below the Assiut Barrage; the following table gives the comparison between them and the corresponding discharge seven days later at the Delta Barrage:—

TABLE 255.—SEEPAGE DISCHARGES IN CUBIC METRES PER SECOND.

Date.	Level.	Assiut Discharge.	Delta Barrage Discharge.	Difference. Discharge.
May 14 . . .	45·74	386	467	+81
June 13 . . .	46·07	520	568	+48
June 30 . . .	46·25	621	627	+ 6

From the above it will be seen that the seepage back into the river between Assiut and the Delta Barrages more than compensated for the losses by pumps and evaporation until the end of June, when they practically balanced.

This bears out the point raised in my last three reports that seepage is an important factor in the supply up to the latter part of June."

As a matter of fact, seepage is a very important factor through the whole of the low supply. The discharges in May are especially valuable records, as the river then was constant. In the middle of June, and more so in the end of June, the "difference" fell because the river was rising and a considerable part of the Assiut discharge was utilised in filling the trough of the Nile.

We see from Table 131 that the mean width of the river at low water between Assiut and the Delta Barrage is 460 metres and the length (370+25 or) 395 kilometres, measured down the centre line of the channel. This gives us an area of 180,000,000 square metres. From Table 44 the evaporation in May is 10 millimetres per day, and therefore the daily loss by evaporation in the reach was 1,800,000 cubic metres, or 21 cubic metre per second. This, added to 81, gives us a seepage asset between Assiut and Cairo of 102 cubic metres per second plus the water lifted by the pumps taking direct from the Nile. These latter are about 18 cubic metres per second, so that the seepage into the river in May 1911 between Assiut and Cairo was certainly 120 cubic metres per second. When the whole of Upper Egypt from Aswan to Cairo is perennially irrigated, the seepage asset between these two places will certainly be 200 cubic metres per second. The importance of this source of supply in summer cannot be too strongly insisted on.

In regulating on the Aswan dam it may be laid down as a sound principle that all water sent down on a falling or stationary gauge ultimately reaches its destination; but if sent down on a rising gauge, all the water needed to fill the trough of the Nile is thrown away. At Aswan

up to the present the loss has been about 400,000,000 cubic metres, or two-fifths of the contents of the lower reservoir.

When regulated on different lines, the Aswan Reservoir will be a far greater asset to the summer supply of the river than it has ever been in the past, as will be seen in Appendix VII., which gives an account of the summer supply of 1913.

We have still to consider the value of the Aswan dam as a source of water power. As a matter of justice the first claim on the power is that of the 200,000 acres of land between Aswan and Armant on both banks of the Nile which could not receive perennial irrigation through the agency of the Esna Barrage. Their water supply would have to be pumped. Now, under present conditions when scattered areas are perennially irrigated it has been shown on page 402 that while the duty of water under wholesale perennial irrigation in Upper Egypt is 40 cubic metres per acre per twenty-four hours for sugar-cane, on detached plots irrigated by pumps it is 50 per cent. more. Assuming that one-half of the area of 200,000 acres is under summer crop, M. Victor Mosséri has thus calculated for us the power needed at the Aswan dam to ensure the summer irrigation of this crop:—

"Let us admit 100,000 acres to be irrigated, between Luxor and Aswan, at the rate of 800 cubic metres per watering every fifteen days.

We have then,

$$100{,}000 \times 800 = 80{,}000{,}000 \text{ cubic metres every fifteen days,}$$

or $$\frac{80{,}000{,}000}{15} = 5{,}333{,}000 \text{ cubic metres per day,}$$

or $$\frac{5{,}333{,}000}{24} = 222{,}000 \text{ cubic metres per hour,}$$

or $$\frac{222{,}000}{3{,}600} = 61 \text{ cubic metres per second;}$$

or, in other words, a discharge of 61 cubic metres per second is sufficient in that region for 100,000 acres in summer.

Now, these 61 cubic metres are to be lifted 9 metres, but we must calculate 10 metres on account of the friction, etc. (manometric height).

We get then:

$$\frac{61{,}000 \text{ litres} \times 10 \text{ metres}}{75} = 8133 \text{ water H.P.,}$$

or $$\frac{8133 \times 100}{70} = 11{,}620 \text{ E.H.P.,}$$

if the efficiency of the pump is 70 per cent.

This is the power required at the pumps. If we admit 20 per cent. loss between the dam and the pumps, we need then at the dam

$$\frac{11{,}620 \times 100}{80} = 14{,}525 \text{ H.P.}$$

Now, this being the required power, what will be the fall of 600 cubic metres per second of water at the dam to ensure it?

I admit that the efficiency of the hydraulic installation will be 75 per cent.—that is to say, 600 cubic metres per second will give per 1 metre fall

$$\frac{600,000 \times 1 \times 75}{75 \times 100} = 6000 \text{ H.P.}$$

If for 6000 H.P. we need 1 metre fall, for the required 14,525 H.P. we need

$$\frac{14,525}{6000} = 2 \cdot 40 \text{ metres fall.}$$

Now, the 11,620 engine horse-power required for the irrigation of the 100,000 acres would have consumed, with the *best engines*, about 12 tons of coal per hour, or, at the rate of £2·5 the ton, would mean

$$12 \times 2\tfrac{1}{2} = £30 \text{ per hour,}$$

or $$30 \times 24 = £720 \text{ per day,}$$

or $$720 \times 30 = £21,600 \text{ per month.}$$

Supposing four months for summer irrigation, until flood we have £21,600 × 4 = £86,400 for summer irrigation beginning in April and ending in August."

If we take R.L. 88·5 as the level of water on the downstream side of the dam when the river is discharging 600 cubic metres per second, we need on the upstream side R.L. (88·5 + 2·5, or R.L.) 91·00. If we turn to Table 126, we see that this level can easily be assured every year.

We have seen in the preceding paragraph that we require a H.P. of 15,000 for the perennial irrigation of those parts of Upper Egypt which cannot be irrigated by barrages. Table 126, however, teaches us that the Aswan Reservoir might be kept at R.L. 95·00 as a minimum without affecting its capacity. This level, with a discharge of 600 cubic metres per second, would give us a H.P. of $\frac{600,000 \times (95 - 88 \cdot 5)}{75} = \frac{600,000 \times 6 \cdot 5}{75} = 50,000$, of which only 15,000 is needed for irrigation. Under the most unfavourable conditions there is a balance of 35,000 H.P. available, which would be increased beyond calculation when the Reservoir was at R.L. 113·00 in low supply, while in flood there is the power available from the flood discharge of the Nile falling 2 metres and upwards. It has been proposed to utilise this for the manufacture of manures. The value of manures to the country will be considered in paragraphs 155 and 180.

152. **Thermal Stresses in the Dam.**—In the discussion on the paper on the *Design of Masonry Dams*,* Sir Benjamin Baker quoted observations made in America to show that at a depth of 1·65 metres inside a wall there might be an annual variation of temperature amounting to 20° F. (11° C.), and inferred the existence of considerable thermal stresses in the material of the wall. He also pointed out then and on a subsequent occasion the difference between the mathematician's dam—an elastic solid at uniform temperature—and the engineer's dam, which was quite a different

* *Min. Proc. Inst. C.E.*, cxv. 107.

TABLE 256.—PHYSICAL CONSTANTS OF SOME BUILDING MATERIALS.

Material.	Granite.	Limestone.	Brick.	Sandstone.	Marble.	Concrete.	Cast Iron.
Density	2·65 to 2·8	2·4 to 2·6	1·4 to 2·2	1·88 to 2·3	2·5 to 2·8	1·7 to 2·4	7·82
Modulus of elasticity	4 to 6×10^5	about $2·5 \times 10^5$	$(1·28 \times 10^5)$*	1·0 to $2·5 \times 10^5$	$2·7 \times 10^5$	2·6 to $3·1 \times 10^5$	7 to 20×10^5
Ultimate compressive resistance	1450	550 to 1100	35 to 460	180 to 540	230 to 1400	140 to 240	6000 to 9000
Ultimate tensile resistance	140	80 to 170	3 to 30	10 to 90	50 to 120	8 to 25	1000 to 1300
Coefficient of expansion	$0·87 \times 10^{-5}$	$1·03 \times 10^{-5}$	0·55 to $1·0 \times 10^{-5}$	1·2 to $1·7 \times 10^{-5}$	$1·04 \times 10^{-5}$	0·8 to $1·3 \times 10^{-5}$	$1·11 \times 10^{-5}$
Specific heat	0·196	0·217	0·19 to 0·24	0·20 to 0·25	0·21	0·16	0·114
Conductivity	0·0081	0·0050	0·0020	0·005 to 0·011	0·0050	0·0022	0·108

The modulus of elasticity = force in kilograms per square centimetre ÷ proportional elongation or compression.
Compressive and tensile resistance are in kilograms per square centimetre.
The coefficient of expansion is for one degree centigrade.

* Sand-bricks.

thing, because there were numerous disturbing influences arising from changes of temperature, contingencies of workmanship, and other causes, which would entirely upset any reasoning based on the assumption of the dam being a perfectly elastic solid at uniform, constant temperature.

The simplified mathematical problem is itself too complicated for a rigorous solution, and the more general case when temperature variations are taken into account is still harder, and this is not the place for an exhaustive discussion of the statics involved. We proceed, however, as promised on p. 23, to estimate as briefly as possible the temperature effects in such structures as the Aswan dam.

Table 256 will be used.

The mean range of air temperature at Aswan between winter minimum and summer maximum is 32·8° C. (see p. 26); but stones, exposed to the baking heat of the sun's rays by day and radiating freely into space at night, must have a temperature range far exceeding this. To be on the safe side, however, we shall consider that the range is only 40°. In granite this will be propagated in the following manner:—

Table 257.—Temperature Range in Granite.

Depth.	Annual Range.	Lag.
0 centimetres	40°·0 C.	0 days.
72 ,,	33 ·2	11 ,,
144 ,,	27 ·7	22 ,,
288 ,,	19 ·2	42 ,,
720 ,,	6 ·5	106 ,,
1200 ,,	1 ·8	176 ,,
1680 ,,	0 ·6	247 ,,

Thus, at 12 metres within the masonry (here regarded as being infinitely thick), there will be a range of nearly 2° with a lag of half a year, so that when the surface is at its minimum temperature the internal point will be at its maximum. There will then exist a temperature gradient of at least 21°/1200 or 0°·0175 per centimetre. In the absence of internal sources of heat, the mean internal temperature at any point will be the mean for Aswan for the year, viz. about 25° C. But masonry built in midsummer will have initially an average temperature of 32°·6, and that built in mid-winter one of 14°·5, or say 33° and 15°.

So far we have neglected the fact that the masonry lay for weeks under wet sacks, kept wet, and with the water trickling over the sides. The effect of this would undoubtedly be to moderate the temperature of the material towards that of the wet-bulb thermometer, which may not unfairly be taken as that at Wadi Halfa (see p. 29), viz. from a mean of 20°·2 in summer to one of 9°·5 in winter. But since the nocturnal

minimum wet-bulb temperature will descend below that of the dry-bulb, viz. $9^\circ{\cdot}1$, and the diurnal maximum wet-bulb will exceed $20^\circ{\cdot}2$, each by several degrees, 20° may be taken as a fair estimate of the range of temperature to which the stones were subjected. If temperature alone were in question, the range assumed above would be about two times too great. But the very means of lowering the temperature—to deluge the stones with water—introduces a further complication. Concrete is known to expand with increasing humidity. Sir Alexander Binnie,* quoted in Buckley's *Irrigation Pocket-book*, found that the expansion of granite concrete due to the absorption of moisture was often as much as that due to summer heat; and Mr L. A. Wade, also quoted by Buckley, found that green sandstone shortened by $\frac{3}{16}$ inch on 20 feet, or $\frac{1}{1200}$, which is equivalent to the change due to 45° C. range of temperature. Mr B. F. E. Keeling † gives the expansion of Abbassia sand-bricks as $\frac{1}{8000}$ on wetting, which is equivalent to the change due to a rise of 13° C. He also found that Portland cement concrete (1 : 3) contracted about $\frac{1}{1000}$ after twenty-five days, which is far beyond any thermal contraction likely to be experienced. The French *Commission du ciment armé* of 1907 found that concrete shrank while hardening in air, but expanded under water.

From these considerations we have thought it not unreasonable to neglect the contraction on drying out, and keep to the higher temperature range. The dampness is necessary to prevent too rapid setting, but in this matter the masonry is indeed between the devil and the deep sea.

The weight of superincumbent masonry will close the dangerous—that is, the horizontal—hair cracks, but the vertical cracks will remain.

As regards the masonry, therefore, we must consider the effect of (i) a uniform change of temperature on a block, and (ii) the existence of a gradient of temperature. We shall have to consider also (iii) the effect of the juxtaposition of two materials of different nature.

The coefficient of expansion of granite is $0{\cdot}87 \times 10^{-5}$. Hence for a change of temperature of 20°, its proportional change of dimensions will be $1{\cdot}74 \times 10^{-4}$. But if the granite is built in so that it is prevented from changing length, it will exert on the limiting material a stress $1{\cdot}74 \times 10^{-4} \times 6 \times 10^5$, or 104 kilograms per square centimetre. The layer of stone near the surface of the dam must be subjected to alternating compressive and tensile stresses of the order of 100 kilograms per square centimetre. From experiments quoted in Appendix II., it appears that syenite cracked and crushed at 20,000 lbs. to the square inch (or 1400 kilograms to the square centimetre). So long therefore as the stress is compressive, the stone will withstand it. When, however, the stone has been put in place in summer, the stress will be tensile, and it may

* *Proc. Inst. C.E.*, clx., 1905, p. 21.
† *Cairo Soc. Jour.*, vii., 1913, p. 98.

reach in winter twice the above value, or 200 kilograms per square centimetre. The tensile resistance of granite is but one-sixteenth to one-twelfth of its compressive resistance, and may be taken therefore as about 140 kilograms to the square centimetre. Thus the surface rock of the Aswan dam is subjected, some of it, to stresses at least 50 per cent. higher than its ultimate strength, and in these circumstances cracks are inevitable. The above table shows that they will occur down to depths of 144 centimetres, and, once the stone is weakened by the initiation of a crack, probably to much greater depths. So far we have treated the material as homogeneous, but the case is even stronger if it is remembered that the masonry is a composite of granite in cement mortar. The constants for concrete are not widely different from those for granite, but the adhesion of the two materials is a source of weakness. Mr R. B. Buckley * quotes observations which go to prove that the adhesion of the mortar joints averaged only 18·2 lbs. to the square inch (1·3 kilograms to the square centimetre), or only one-hundredth of the possible tension. It is clear that the joints may be expected to open under the above-mentioned tension long before the stone cracks.

As the dam is 2000 metres long, the total extent of the cracks from one end to another may be expected to approach $2000 \times 1{\cdot}74 \times 10^{-4}$, or 0·348 metre on the surface in the middle of winter. In spring and autumn on the average the cracks will have closed up, and in summer the entire dam will be under thermal compression, and any cracks existing then must be due to the contingencies of workmanship to which Sir Benjamin Baker referred.

We consider next the effect of a temperature gradient. A slab of stone, built-in and subjected to a transverse temperature gradient, will tend to expand differently on its two faces, and will be subjected to tangential stresses normal to the gradient as well as to the stresses due to general change of temperature. The tendency of these will be to cause curvature of the slab, with the concavity in the direction of the diminishing temperature, and, where the slab lies on the surface, to cause stripping; but it seems likely that their effects will be small, and we content ourselves with this indication.

There remains the third case, where materials of different nature are in contact; for example, cast iron and granite. Two factors have to be considered: namely, the relative coefficients of thermal expansion, and the rate at which heat diffuses through the substances. The coefficients of expansion for granite and cast iron are respectively $0{\cdot}87 \times 10^{-5}$ and $1{\cdot}11 \times 10^{-5}$ per degree centigrade. The relative expansion will therefore be $0{\cdot}24 \times 10^{-5}$ per degree, and, as we may easily have ranges from 20° below to 20° above the mean, the relative expansions may be taken as averaging

* *Irrigation Pocket-book* (Spon, London, 1913), p. 347.

$0{\cdot}48 \times 10^{-4}$, or roughly one-fourth of that which we have seen possible for granite alone. If bolted to the granite, the cast iron will exert on the bolts an alternating stress of about $8 \times 10^5 \times 0{\cdot}48 \times 10^{-4}$, or 38 kilograms per square centimetre section of the iron. If cemented to the stone, the joint will have to withstand a tangential stress of the same amount per centimetre of breadth. In either case the union will not be a happy one, and the iron will eventually work loose.

The coefficient of diffusion (diffusivity) for granite is 0·0155, and for cast iron 0·121, or about eight times that for granite. Heat will diffuse through a sheet of cast iron eight times more rapidly than through the stone, and accordingly an iron slab, laid on granite and subjected to the full radiation of the solar rays or to the effects of the heated air, will become heated throughout to a high degree long before the granite has had time to take up the effect. The result will be that the stresses just calculated, on the assumption of equal temperatures throughout, will be considerably increased.

As to the effect of these stresses on the stability of the dam, where the cracks are vertical, the stability will be unaffected; but where the cracks are horizontal (which fortunately will be but rarely) and on the upstream face, vertical water pressures will be admitted and the stability will be lessened.

Cracks in cyclopean masonry have formed the subject of a study by Mr C. S. Gowen, M.Am. Soc. C.E.,* whose chief conclusions are:—

(i) The more compact the masonry the greater the likelihood of cracks due to change of temperature.

(ii) The localisation and extent of such cracks are due primarily to the differences in sectional areas, arising from unequal progress in the masonry, or from abrupt changes in section.

(iii) The most pronounced cracks arise from varying sectional masses laid in warm weather or summer.

The average temperature and range were rather less than at Aswan.

Now we know from experience that:—

(1) So far no dams have failed from thermal stresses alone.

(2) Practically all the real failures can be ultimately traced to inferior foundations. Poorly designed dams on strong foundations have stood, while poorly designed dams on poor foundations have failed.

(3) When serious cracks have occurred in structures owing to poor design or poor foundations, they have been occasionally confounded with those due to thermal stresses.

Combining our theoretical and practical knowledge, we may conclude that:—

(*a*) Dams should be built with a curvature convex to the reservoir. As

* *Proc. Am. Soc. C.E.*, April 1908, p. 316. We are indebted to Mr MacDonald for this reference.

the dam contracts and expands, the effect will be to increase or decrease the curvature and not to tear the joints open.

(*b*) Signor Torricelli's idea of each set of ten sluices being built on a curve, with massive abutment piers between, was sound.

(*c*) Large masses of iron exposed to the sun or heated air on their whole surface and incorporated in the dam, are a source of weakness. It is better to have the whole dam of homogeneous masonry.

(*d*) Since masonry built in winter is liable to compression in summer, and masonry built in summer is liable to tension in winter, while dampness approximates the thermal conditions to those of winter, it is essential that all masonry should be kept deluged with water. It may be noted that this was done very effectively at the Aswan dam.

At the close of paragraph 151 we considered the question of the water power of the Aswan dam. There are two other sources of power in Egypt, which have been but little exploited. Outside of Alexandria there are scarcely any *windmills* in the country. The Land Allotment Company (page 495) erected two windmills for drainage purposes, but after a year's trial abandoned them. Then there is the *power of the sun*, which so far has not been exploited. Mr Frank Shuman, representing the Sun-power Company of Tacomy, Philadelphia, U.S.A., is conducting some experiments near Cairo to produce steam by concentrated sun-power. The climates of Middle and Upper Egypt and the North Sudan should be very suitable for the utilisation of the power of the sun (see Table 3, page 23).

Coal near Aswan costs £2·5 per ton (page 752), but near Alexandria and Cairo it costs much less. To enable an estimate to be made of the competition between sun-power and coal, we give the following information from the Irrigation reports for 1911.

TABLE 257A.—DUTY OF PUMPS.

Name of Pumping Station, and Page for Reference.	Lift in metres.	Coal in Tons per million cubic metres lifted.	Cost of One Million Cubic Metres lifted. £	Coal per W.H.P. per hour in kilograms.	Cost of Coal per metric ton.	Remarks.
Atfeh (384) .	2·63	29·2	63·6	3·00	...	Amria is a new pump for pumping in flood for irrigation of 7300 acres. Station cost £14,177.
Mex (394) . .	3·01	15·9	33·2	1·43	1·498	
Kassassin (503) .	2·62	36·7	87·8	3·78	1·814	
Korimat (419) .	5·79*	18·8	49·5	1·20	1·573	
,, .	0·80	...	36·9	1·91	...	
Elessi (419) .	5·79*	21·0	66·2	1·08	1·532	
Amria . .	low	12·7	49 9	1·65	1·480	

* These figures appear to be excessive.

CHAPTER XIV.

AGRICULTURAL.

153. The Fertility of Nile Silt.—154. The Agricultural Value of Reservoir Water.—155. Manures.—156. Agricultural Notes in 1897.—157. Areas under Crop.—158. Duty of Water.—159. Cotton, Rice, and Winter Crops.—160. Sugar-cane.—161. Tobacco.—162. The Date Palm.—163. Dates of Sowing and Harvesting.—164. Cost of Raising and Yield of Crops.—165. Areas protected by Pumps and Sakias.—166. Dates of Sharaki Irrigation.—167. Cotton Worm and Boll Worm.—168. Weights and Measures.—169. Improvement in Quality and Yield of Cotton.—170. Fisheries.

153. **The Fertility of Nile Silt.**—"The Garden of the Lord, the land of Egypt," is the earliest description of the valley of the Nile in Holy Writ. "Vidi viridem Ægyptum" was the verdict of the Roman world. "Green, inexpressibly green, is the vale known as the land of Egypt" is the observation of a modern traveller. To what does Egypt owe its extraordinary fertility and recuperative ability? We reply that it owes it to the high fertilising power of the water of the Nile. This is an essential link in several of the arguments in this book, and on this account we desire to emphasise here the proof of this position. Emphasis is the more necessary in that there is a recent tendency to decry the value of Nile silt and assign the fertility to the abundance of water.

If reference is made to Table 9, it will be found that the best soils are those that on the whole differ least from Nile silt, and the worst those that differ most. In paragraph 1 Dr Hume states that the volcanic materials of which Nile deposit is formed are producers of some of the most fertile soils on the face of the earth. In paragraph 45 it will be seen that the first object of Colonel Ross's improvement works in Upper Egypt was "the free circulation of good *red water*." In paragraph 46, the first of the four main elements on which rents depend in the basins is said to be "a plentiful supply of *red water*." This is borne out by every statement in paragraphs 50 and 68, where the different provinces are described in detail. Paragraph 74 has the following sentence: "Now *red water* contains not only chemicals, but sand, bacterial life, and food for bacteria in the soil." In paragraph 120, M. Naus states that for sugar-cane, "*red water*, when the flood comes, is as good as manure," and then gives reasons for saying so. CHAPTER VIII. is devoted to the means adopted for securing abundance of Nile silt to the highly cultivated lands of the perennially irrigated

tracts. In CHAPTER XII. we see that the Aswan dam owes its success to the fact that though it impounds the excess supplies of the winter for use in summer, it in no way interferes with the flood and allows a free passage to the muddy waters of the Nile.

We now supplement these remarks with quotations from well-informed writers on the use of the muddy waters of the Nile and of the floods of rivers in countries outside of Egypt.

"From the rocks of Egypt only a poor and calcareous soil could be derived, but the rich Nile mud is obtained from rocks far to the South" (A. Linton, in *Egyptian Agriculture*, p. 28).

"In Egypt, Nile water is the only source from which fresh soil can be obtained. For improving sandy soil this deposit of mud is very valuable. Well water is naturally devoid of suspended matter and does little to enrich the soil" (Linton, *op. cit.* p. 45).

The whole of Mr G. P. Foaden's article in CHAPTER VIII. of *Egyptian Agriculture* is replete with instances of the fertility of Nile mud. We advise anyone who is in doubts to read his article, which is too long for reproduction here. Still we cannot forbear some extracts :—

"Any increase in the quantity of water available for irrigation purposes without a corresponding increase in the manure supply is often of doubtful benefit" (*op. cit.* p. 213).

"Sir Edward Buck, referring to land near Ajmere (India), states as follows:— 'Irrigation from tanks is lavish, and is put on to land which it has robbed of its fertility, as the manure supply, before deficient, is now wholly insufficient to restore fertility. Given unlimited manure, water will raise the rental of land to R. 50 (£3·25) an acre. With no manure it will sink to R. 1 (6½ piastres) an acre'" (p. 213).

"Where there is . . . land enriched by silt the supply of water alone may suffice" (Dr Voelcker quoted, *op. cit.* p. 214).

"Irrigation cannot be carried beyond the limits where the supply of available manure is fixed" (*Report by Director of Agriculture*, Bombay, 1888–91, quoted, p. 214).

"*Nile Mud.*—In a broad sense, this may be looked upon as the manurial substance which has contributed more towards the fertility of Egyptian soils than any other. . . . As is well known, the red muddy water of the Nile deposits, during its sojourn in the basins, a valuable layer of rich mud. The soil is thus enriched annually, and, as already mentioned, as long as this system was practised in Lower Egypt there was not that need for manure which has arisen to-day" (Foaden, *op. cit.* p. 225).

"Consequently, at soluble commercial fertiliser rates, the value of the mud deposited on an acre is approximately equal to £1·50" (*op. cit.* p. 229).

"In the same work Mr Lang-Anderson proposes an adoption of a rotation of basin and perennial irrigation. 'In this way,' he says, 'all the land would have a thorough renovation with rich Nile mud every second year, and the noted fertility of Upper Egypt would be maintained."

One has only to compare the richness of the land in the Sudan watered

by the red flood of the Blue Nile with the poorness of that watered by the anæmic White Nile to see the difference.

"While the wisdom of one age succeeded in restricting within bounds the tidal water of the river (Trent), it was left to the greater wisdom of a succeeding age to improve upon this arrangement by admitting these muddy waters to lay a fresh coat of rich silt on the exhausted soils. . . . By careful attention to the currents, the expert warp farmer can temper his soil as he pleases. When the tide is first admitted, the heavier particles, which are pure sand, are first deposited; the second deposit is a mixture of sand and fine mud, which, from its friable texture, forms the most valuable soil; while, lastly, the pure mud subsides, containing the finest particles of all, and forms a rich but very tenacious soil. . . . The silt deposited after warping is exceedingly rich and capable of carrying any species of crop" (*Ency. Brit.*, 11th ed., vol. xiv. p. 845).

"The second (exceptional excellence of the River Nile) is hardly less valuable, and consists in the remarkable richness of the alluvium brought down the river year after year during the flood" (*Ency. Brit.*, 11th ed., vol. xiv. p. 847).

"The water of turbid streams has generally been held in great esteem for irrigation, on account of its high fertilising value" (*Irrigation and Drainage*, by Prof. F. H. King, p. 259)

"The Durance, in France, is famous for its fertile waters, and they carry at the ordinary maximum $\frac{1}{33}$ of their weight of sediment. . . . Where such waters are used year after year on poor lands, the improvement becomes very great, while on the better lands a high and permanent degree of fertility is maintained indefinitely, with heavy yields per acre as the result" (King, *op. cit.* p. 260).

"To enrich the soil, the turbid flood should be admitted and kept standing in the enclosed area long enough to throw down its fertilising matter, and then run off" (Hanbury Brown, *Irrigation*, p. 255).

"The superiority of the river water over that of wells is demonstrated by the fact that near the heads of the Punjab canals the cultivators prefer to pay canal rates and to lift the water from the canals rather than to lift it from wells, although the canal level and the spring level are about the same" (Buckley, *Irrigation Works of India*, p. 28).

"The cultivators in Orissa and Behar, during the rainy season, when the rice crop is under irrigation, will often endeavour to drain the water off their fields and irrigate them again from the canals whenever a freshet in the river brings an extra quantity of silt into the water" (Buckley, *op. cit.* p. 47).

These extracts, which might easily have been multiplied many-fold, show that experts not only in irrigation but also in practical agriculture are unanimous as to the value of river silt as a fertiliser in India, Italy, France, England, and North America; and the experience of centuries of Egyptian history proves that the mud of the Nile flood is rich indeed and Egypt is fortunate in being, as Herodotus called it, the gift of the Nile.

154. **The Agricultural Value of Reservoir Water.**—Reservoir water has no direct manurial value, but its indirect value lies in its supplementing the summer supply of the Nile, when, without its aid, large areas could not be put under the summer crops of cotton, sugar-cane, and rice.

The reservoir water starts them, while the rich red waters of the Nile flood mature them. Cotton requires 3000 cubic metres per acre of reservoir water. Sugar-cane in the southern parts of Upper Egypt requires 4500 cubic metres, while rice in the Delta requires 4000 cubic metres. Rice would need more, proportionately to cotton, were it not that it is sown much later than cotton. If we consider rice as occupying one-seventh of the summer area, we may neglect the southern Upper Egypt sugar-cane area, as it is very small in extent. We thus find that an acre of summer crop requires 3300 cubic metres of reservoir water. Under the most skilful manipulation we may consider 25 per cent. of the Aswan Reservoir as unavoidably wasted, and therefore an acre of summer crop requires to have stored in the reservoir 4400 cubic metres. Each milliard of cubic metres of water suffices therefore for the irrigation of 225,000 acres of summer crop; and as cotton is sown only in alternate years, and one acre of cotton means two acres of perennially irrigated land, we may say that each milliard of cubic metres of reservoir water suffices for 450,000 acres of perennially irrigated land. The reservoir water is applied for some three months per annum, and the Nile itself supplies the water for the remaining nine months.

The change from basin to perennial irrigation allows the Government to increase the land tax by £·50 per annum, and therefore one milliard of cubic metres of reservoir water adds £225,000 per annum to the land tax of the country. This is the increase to the direct taxes; the indirect benefits from extra railway transport, imports, and tobacco are additional to this. The increased revenue from customs alone will amount to as much as the direct taxes, and it is well within the mark to estimate the value of a milliard of cubic metres of reservoir water to the Treasury as £500,000 per annum.

155. **Manures.**—This subject was thus treated in the second edition of this work and in *The Nile in 1904* (p. 69):—

"The ordinary *manure* of Lower Egypt is the urine of farm cattle, with the ammonia fixed by dry earth, which is spread under the cattle and removed daily, and collected in heaps outside the farms. The dry atmosphere and the dry earth of Egypt combine to fix all the valuable ingredients of the urine. Before the flood, the manure is carried to the fields which are going to be planted with Indian corn, and in this way every field receives manure once every two years. For special crops, as melons, gardens, etc., pigeon guano is used.

If one is desirous to further study the question of *manures and of the nitrate deposits* in the deserts south of Kena used from time immemorial, but brought to the notice of the Egyptian Government by Mr E. Floyer, of the Telegraph Department, reference should be made to a paper entitled *Nile Cultivation and Nitrates*, read by Mr J. B. Fuller (now Sir Bampfylde Fuller, K.C.S.I.), before the Agricultural Society of England, and embodied in their third series, vol. vii. part 4, 1896. A pamphlet entitled *Manures in Egypt and Soil Exhaustion*, by Dr Mackenzie and

Professor Foaden, of the Cairo College of Agriculture, printed by the Egyptian Government in 1896; and another on *Cotton Culture in Egypt*, by Mr G. P. Foaden, of the School of Agriculture, published by the United States Government as Bulletin No. 42 of the United States Department of Agriculture, Office of Experimental Stations in 1897; contain a mass of the most valuable information."

"While basin irrigation is followed by the winter crops of wheat, beans, clover, barley, flax, lentils, vetches, and onions, perennial irrigation allows of all the above winter crops and in addition the summer crops of cotton, sugar-cane, oilseeds, gardens, and orchards. It will readily be understood that all this double cropping necessitates a very free use of manures.

It would be a healthy innovation indeed, if the provision of suitable manures were to be considered as an essential part of a project for providing perennial irrigation. The day is not far distant, I believe, when governments which provide irrigation works will also provide manures, and sell the water and the manures together, one being as essential as the other; I know well, from observation, that a well-manured field needs only half the water that a poorly manured field does; and in years of drought and scarcity manures almost take the place of irrigation. Why should there not be a manure rate as well as a water rate? Here in Egypt, the numerous ruins of old-world cities have hitherto provided manure for a great part of the perennially irrigated lands; but these are being fast worked out, and other sources must be sought for. Farm-yard manure will never suffice for the intense cultivation in this country.

Egypt possesses, in the vicinity of Luxor, natural beds of nitrates of unlimited extent, which come down to the river's edge. They contain only about 6 per cent. of pure nitrates; but as they are on the edge of the Nile, in a perfectly cloudless and very dry country, it might be possible, with the aid of the plentiful supply of water always at hand, profitably to extract pure nitrates. The demand for nitrates is without limit in the Nile Valley, as Nile water, though rich in everything else, is poor in nitrates."

We have seen, moreover, in paragraph 3 that Dr Hume speaks of the existence of a limestone rich in phosphate of lime at Sebaia, north of Mahamid and south of Esna. This phosphate was quarried for a time and works begun, but they were not continued. Dr Hume states that the average percentage of nitrate noted in the clays is 8·4, while the maximum is 34 per cent.

It is the intention of the Egyptian Government to utilise part of the power of the Aswan dam to manufacture pure nitrates from limestone or from these rocks and sell them to the fellahin. If the Egyptian Government can perform this task on a scale commensurate with its importance, it will have been the first in the world to introduce a manure rate, as it was undoubtedly the first to introduce a water rate.

We have already stated that Nile water, though rich in phosphates and potash, is poor in nitrates. This poverty is ordinarily counteracted by a rotation of beans, lentils, and clover, especially clover. With the intense cultivation which is practised to-day, the use of nitrates has greatly increased as the following table will testify:—

TABLE 258.—QUANTITY AND VALUE OF MANURES IMPORTED FROM 1909 TO 1912.

			Total Imports. (1)	Varieties of Manures. Nitrate of Soda. (2)	Super-phosphate. (3)	Sulphate of Ammonia. (4)	Cyanamide. (5)	Sulphate of Potash. (6)	Other Manures. (7)
1909	Quantity	Tons	21,165	18,530	2,255	354	...	...	26
	Value	£	178,014	166,464	7,276	4,047	...	...	227
	Mean price	£	8·411	8·983	3·207	11·432	...	...	8·731
1910	Quantity	Tons	35,559	30,505	3,318	1,660	...	...	76
	Value	£	296,711	265,621	11,312	19,253	...	...	525
	Mean price	£	8·344	8·707	3·409	11·598	...	...	6·908
1911	Quantity	Tons	59,962	48,771	9,497	1,639	...	...	55
	Value	£	496,644	446,730	28,034	21,506	...	...	374
	Mean price	£	8·283	9·160	2·952	13·121	...	...	6·800
1912	Quantity	Tons	70,089	56,047	11,459	1,650	728	144	61
	Value	£	667,926	597,885	37,807	24,191	6,620	1,177	246
	Mean price	£	9·529	10·668	3·299	14·661	9·093	8·174	4·033

The use of nitrates is followed by speedy results, confirmed by experiments carried out by the Egyptian branch of the Chilian Nitrate Committee. The Department of Agriculture sent one of its inspectors to look round some of the fifty-three experimental fields in Giza, and to be present when some of the produce was weighed. We now quote from a translation of Circular No. 22 of the Agricultural Department:—

"Every acre of maize was treated with 150 kilograms of nitrate—75 of which were applied, at thinning before the first watering, which comes after *mohayâh*; and the rest, at hoeing, before the second watering after *mohayâh*. This was done after sifting the manure through a fine sieve to make sure that it had been reduced to a fine powder.

Three or four times the amount of fine earth was mixed up with nitrate by the following method: A certain area of land is covered thickly with nitrate and then the fine earth is piled on top of it and levelled. The cultivator then cuts the heap with a *fâs* in one direction, and then the mixture of earth and nitrate is thrown back on the heap. The same work is repeated three times, the heap being cut away each time in a different direction. The result is that the manure is so thoroughly mixed with the soil that it is impossible to distinguish one from the other.

The Commission wished to prove that the application of the manure by the *takbîsh* method is more advantageous than that of dispersing it broadcast. It used the *takbîsh* method in most of the experimental fields and scattered the manure broadcast in a few of them. The result showed that fields manured by the *takbîsh*

method produced a greater yield than those in which the manure was scattered broadcast. The excess of production resulting from the use of nitrate was greater in maize sown after *berseem* than in that sown after wheat.

In conclusion, we can say that between the acre manured in the *takbîsh* method, with 150 kilograms of nitrate, and the other manured with *baladi* or *kufri* manure, there is a difference of four ardebs and a half, on the average, in maize sown after *berseem*, and three and a half ardebs in maize sown after wheat. Besides this the difference between the expense of the nitrate and that of *baladi* or *kufri* is £·75 per acre : the former costing £1·80, and the latter £2·55, on the average.

Therefore the profit gained by the substitution of nitrate for *baladi* * or *kufri* † manure was not less than £4 to £5 per acre. Besides this, is the advantage which comes from keeping the *baladi* manure for the crop following maize.

The Commission made calculation of the amount of increase due to using nitrate. They found that in two acres, one of which was treated with nitrate and the other with *baladi* or *kufri*, the excess of the former over the latter was as follows :—

Number of ears of maize	10 per cent.
Weight ,, ,, ...	20 per cent.
Proportion of grain to core	5 per cent."

Though nitrates are so beneficial, the continuous use of chemical manures without a free use of the muddy water of the Nile flood is to be deprecated, owing to the binding effects of such manures on the dense clay soil of Egypt unless their action is modified by the silt-laden waters of the flood.

156. **Agricultural Notes in 1897.**—We place here for record from the Second edition of this work varied information which was collected with great care previous to 1897 :—

"During flood the irrigation is practically 'flush' everywhere; during winter it is 'flush' in many localities by rotation, while during summer it should be generally 'lift.' To prevent excessive infiltrations, in all but rice lands, it is better to keep the water surface low, and lift the water during summer. *The water is lifted* on to the fields by any of the following methods :—

1. *Engines and pumps ;*
2. *Sakias*, *tabuts*, *screws*, etc., worked by oxen ;
3. *Shadufs*, worked by men ;
4. *Natâlis*, worked by men.

1. *Engines and Pumps.*—As a rule, *portable engines and centrifugal pumps* are used, owing to their great convenience and power to resist wear and tear. The 8-h.p. engine and the 8-inch pump are the machines most commonly used. The engine is placed on a plot of level ground, and the pump supported on a wooden trestle, or fixed inside a cheap masonry well. Where capital is available and the estate a large one, a stationary engine and pump are of course preferred. Where the lift is above 3 metres, centrifugal pumps are almost always preferred; where the lift is under 3 metres, water-wheels of different kinds are also employed. The fuel used is ordinary coal, though occasionally one sees cotton and bean stalks. In Upper Egypt, where coal is dear, wheat straw and Indian corn stalk are often used. The engines are generally worked for twelve hours per day.

* Farm-yard manure. † Manure from the ancient ruins.

2. *Sakias* (*or Persian wheels*) are used where the lift is over 3·5 metres, and *tabuts* (or wheels delivering water at the periphery) when the lift is under 3 metres. They are driven by a single animal, or a pair: cows and female buffaloes are generally employed. It is not an uncommon sight to see the wheel replaced by an Archimedean screw driven by oxen when the lift is about 1 metre or 1¼ metres. They lift the water to the required height, and not from 1 metre to 1½ metres higher than necessary, as is done by the tabuts and sakias.

3. *Shadufs*, or poles with bucket and counterpoise, are used where the irrigation is temporary, or where the men cannot afford a sakia. Where the lift is only 1 metre they are often replaced by *Archimedean screws* worked by hand.

4. *Natâlis* (Indian *bôkas*), or buckets worked by strings, are used where the lift is under 1 metre, and where, owing to the fluctuating supply, flush irrigation is frequent.

The *sizes of pumps* recommended *practically* for different sized engines and different lifts are detailed below:—

Portable Engine	4 H.P.	6 H.P.	8 H.P.	10 H.P.	12 H.P.	14 H.P.	16 H.P.	20 H.P.	25 H.P.
	inches	inches	inches	inches	inches	inches	inches	inches	inches
1 metre lift .	6	8	10	14	16	18	20	24	30
2 metres lift.	5	8	10	12	15	16	18	22	30
3 ,, .	5	8	10	12	15	16	18	22	30
4 ,, .	4	6	8	10	12	14	16	20	24
5 ,, .	4	6	8	10	12	14	16	20	24

The ordinary rule is to make the pump the same number of inches as the engine has h.p., but this means waste of power in low lifts.

As a result of sixty very carefully made observations in the Delta, I found that with the *ordinary portable engines and pumps in use in the country the discharge was ⅔ cubic metre per h.p. per minute.* By h.p. is here meant the nominal h.p. of commerce. In other words:—

A 6 h.p. engine and pump would deliver 4·0 cubic metres per minute.
8 ,, ,, ,, 5·3 ,, ,,
10 ,, ,, ,, 6·6 ,, ,,
12 ,, ,, ,, 8·0 ,, ,,

Sakias are used for high lifts and *tabuts* for low lifts. They have the duty detailed below:—

Lift in metres.	Discharge in cubic metres per minute through the 12 hours.	Acres of Cotton irrigated in 12 hours.	Acres generally put under Cotton on a Sakia or Tabut. With 1 Ox.	With 2 Oxen	With 3 Oxen	Remarks.
1 to 2	·40	·80	8	14	20	
2 to 4	·25	·50	4	8	12	According to M. Audebeau Bey, the efficiency of the tabut is from 28 to 35 per cent.
4 to 6	·20	·45	4	7	11	
6 to 8	·15	·33	3	6	10	

If the oxen are hired, the charge per pair of oxen per twelve hours will be £·20, but almost invariably home stock is used.

A *shaduf* worked by one man gives the following duty :—

Lift in metres.	Discharge, cubic metres per minute.	Acres of Cotton or Corn Irrigated in 12 hours.	Acres generally put under Cotton or Corn.	Remarks.
0–2½	·050	·10	1	When the lift exceeds 2½ metres, two shadufs are used; when the lift exceeds 4½ metres, three shadufs are used.

If labour is taken at 3 piastres per day of twelve hours in Lower Egypt and 1½ piastres per day of twelve hours in Upper Egypt, the cost of irrigation can be worked out. Generally the man works for his own crop. Two men working at one *shaduf* in alternate spells of one hour, will do 50 per cent. more work than the above.

With a *natâli*, four men working in relays of two men can irrigate 1 acre in twelve hours with a ¼-metre lift, ¾ of an acre with a ½-metre lift, and ½ an acre with a ¾-metre lift.

With an *Archimedean Screw* two men do the same work that four can do with a *natâli.* M. Audebeau Bey has found the efficiency to be 50 per cent.

In Upper Egypt, 1897.

Cotton sowing begins on the 20th February and terminates on the 5th April. The cotton harvest begins on the 5th August and terminates on the 15th October. The land receives the *taf el sharâki* watering before ploughing, and then a watering when the seed is sown. About twenty days subsequently it receives a second watering, a third watering after another thirty or forty days, and then a watering every fifteen days. Up to the end of July the land received nine waterings. This means some 3600 cubic metres per acre. In August and September the crop receives four waterings, and one watering in October with the red water of the flood, or some 2000 cubic metres per acre. The land is then very heavily irrigated and the winter crop is sown, which receives some two waterings, or another 1500 cubic metres per acre. Allowing 5 cubic metres per acre per day lost in the canals and watercourses during the summer, we have an additional 900 cubic metres per acre per annum. Such land therefore receives in the twelve months some 8000 cubic metres per acre, or a vertical depth of 1·90 metres.

Sugar-cane sowing begins in the last week of February and terminates on the 5th April. The harvest begins on the 15th December and terminates on the 15th March. It is irrigated steadily every twelve or fifteen days through summer and flood up to the 15th November, and after that if there is any frost in the winter. During summer it receives ten waterings.

A kantar of canes is almost the same as a cwt., and about 22½ kantars make a ton. A ton of sugar-canes yields for all practical purposes a tenth of a ton of sugar.

Gedi or *Summer Sorghum* in the basins is sown from the 20th March. Sowing terminates on the 20th April. The harvest begins on the 1st August and terminates

on the 15th August. This crop is watered from wells in the fields by shadufs and by sakias, and is irrigated every ten days until it is harvested. It receives on an average a volume of water of some 3000 cubic metres per acre.

Nabari or *Flood Sorghum* is sown either on the Nile berms or in the basins. Sowing begins on the 5th August and terminates on the 5th September. The harvest begins on the 5th December and terminates on the 25th December. This crop is watered by shadufs and sakias working on the Nile or on the canals, and is irrigated every ten or fifteen days till the 15th November. The amount of water put on the acre is about 2250 cubic metres.

Winter Crops, such as wheat, beans, clover, and barley. Sowing begins on the 5th October and terminates on the 30th November. The barley and bean harvest begins on the 10th March and terminates on the 10th April. The wheat harvest is about a month later. In the basins such lands are not watered as a rule. In Esna and Kena, where the hills produce nitrates, the cereals are manured and irrigated two or three times, from wells in the fields and from the Nile.

Lower Egypt, 1897.

Cotton sowing begins on the 20th February and terminates on the 5th April. The harvest begins on the 20th August and terminates on the 10th November. The cotton is picked two or three times. This crop generally follows clover. The land receives one watering before ploughing and another when the seed is sown. The next watering is given after twenty days, and then there is a break of forty days. Subsequently the cotton is irrigated every fifteen or twenty days. Before the flood the land receives from seven to eight waterings, or some 3000 cubic metres per acre. In flood and winter the same rules apply to the irrigation as in Upper Egypt. Land in Lower Egypt under cotton in summer and under winter crops in winter receives about 7500 cubic metres of water per acre, or a vertical height of 1·8 metres. When drains exist and the clover is washed and drained, of course a larger quantity of water is used.

Indian Corn or *Durra* (*Amerikâni* and *Baladi*). Sowing begins on the 5th July and terminates on the 30th August. The harvest begins on the 15th October and terminates on the 30th November.

The American variety is irrigated when it is sown, then twenty days after, and subsequently every ten or twelve days till it is reaped. The Egyptian variety is watered at sowing, fifteen days after sowing, and then every twelve or fifteen days till it is reaped.

Sultâni Rice is sown from the 5th May to the 5th June. The harvest is reaped during November. This crop needs as a minimum 40 cubic metres per acre per day, and in flood receives as much as the drains can possibly carry away.

Sabaini Rice is sown as soon as the flood arrives, about the 5th August, and is sown up to the 5th September. It is reaped at the same time as the Sultâni, and receives as much water as the drains can dispose of.

Winter Crops, wheat, beans, barley, and clover. Sowing begins on the 25th October and terminates for wheat on the 10th December, beans on the 20th, and barley on the 30th.

The bean and barley harvest lasts from the 15th April to the 5th May, while the wheat harvest is some twenty days later. Clover is irrigated later, till the 1st June.

The wheat is irrigated about thirty-five days after sowing, and then once again. Beans are irrigated twenty days after sowing, and then once again. Barley is irrigated once about forty days after sowing.

The *Theoretical Rotations* of crops in the rich lands in Lower Egypt are as follows:—

	Winter.	Summer and Flood.
1st year	Clover or fallow	Cotton.
2nd year	Wheat or clover	Indian corn.
3rd year	Beans or clover	Indian corn.

In the poor lands they are as follows:—

	Winter.	Summer and Flood.
1st year	Clover	Cotton.
2nd year	Clover or barley	Rice.
3rd year	Barley	Fallow.

The *Actual Rotations* of crops are as follows:—

In the rich lands—

	Winter.	Summer and Flood.
1st year	Clover	Cotton.
2nd year	Beans or wheat	Indian corn.
	and so on.	

In the poor lands—

	Winter.	Summer and Flood.
1st year	Clover	Cotton.
2nd year	Clover	Cotton.
3rd year	Barley	Rice or fallow.

For lift irrigation from Persian wheels or sakias, the *sizes of beds* vary from 10 metres × 2 metres to 10 metres × 5 metres; for irrigation from pumps the sizes of beds vary from 10 metres × 10 metres to 20 metres × 15 metres. With flush irrigation the beds vary from the small sizes used for lift irrigation to the whole field.

The *quantity of seed sown per acre* is as follows:—

Wheat, after cotton	8 kêlas.
,, Indian corn	7 ,,
,, fallow or flood	6 ,,
Barley, if ploughed	6 ,,
,, after fallow or flood	5 ,,
Indian corn	3 ,,
Sultâni rice	2 ,,
Sabâini ,,	4 or 5 kêlas.
Sugar-cane	50 to 100 kantars.
Clover	2 kêlas.
Beans, if ploughed	8 ,,
,, (in basins)	6 ,,
Cotton	3 to 6 kêlas."

157. **Areas under Crop.**—We have treated fully in CHAPTER I. of the

soil and water of Egypt, and lightly of the principal crops. We recapitulate here :—

The total cultivated area of Egypt may be taken as 5,351,000 acres, of which 2,251,000 lie in Upper Egypt and 3,100,000 in Lower Egypt. The whole area of Lower Egypt is considered as perennially irrigated, while in Upper Egypt 1,287,000 acres are under basin irrigation and 964,000 acres under perennial. The area under basin irrigation is therefore 1,287,000 acres, and under perennial irrigation 4,064,000 acres.

The principal crops of Egypt are given in the following table. According to it the 5,351,000 acres of cultivated land in Egypt produce 7,724,000 acres of crop annually, or 2,373,000 acres are double cropped. This means that 45 per cent. of the acre is double cropped.

TABLE 259.—PRINCIPAL CROPS IN EGYPT PER ANNUM IN ACRES.

Name of Crop.	Upper Egypt.	Lower Egypt.	Egypt.	Remarks.
Winter.				
Wheat	605,000	656,000	1,261,000	
Beans	463,000	97,000	560,000	
Barley	188,000	201,000	389,000	
Clover, etc. . . .	625,000	932,000	1,557,000	
Total winter . .	1,881,000	1,886,000	3,767,000	
Summer.				
Cotton	307,000	1,335,000	1,642,000	
Millets and maize . .	137,000	33,000	170,000	
Sugar-cane . . .	44,000	5,000	49,000	
Rice	...	233,000	233,000	
Other crops . . .	32,000	54,000	86,000	
Total summer . .	520,000	1,660,000	2,180,000	
Flood.				
Millets and maize . .	545,000	1,131,000	1,676,000	
Rice	15,000	39,000	54,000	
Vegetables . . .	6,000	9,000	15,000	
Total flood . .	566,000	1,179,000	1,745,000	
Gardens . . .	17,000	15,000	32,000	Throughout the year.
Total for the year .	2,984,000	4,740,000	7,724,000	

The detailed crops for 1911–12 have been placed before us, and from them we extract the following detailed information :—

Flood, 1911—Maize . . .	1,531,000 acres		
Millets . . .	167,000 ,,		
Rice	25,000 ,,		
Vegetables, etc. .	12,000 ,,		
		1,735,000 acres	
Winter, 1911–12—Wheat . . .	1,283,000 ,,		
Beans . . .	518,000 ,,		
Barley . . .	364,000 ,,		
Clover . . .	1,368,000 ,,		
Vetches . . .	23,000 ,,		
Onions . . .	27,000 ,,		
Lentils . . .	62,000 ,,		
Flax	7,000 ,,		
Saffron . . .	1,000 ,,		
Fenugreek . .	57,000 ,,		
Lupins . . .	10,000 ,,		
Cow pea . . .	1,000 ,,		
Others . . .	16,000 ,,		
		3,737,000 ,,	
Summer, 1912—Cotton . . .	1,722,000 ,,		
Rice	200,000 ,,		
Maize . . .	136,000 ,,		
Sugar-cane . .	50,000 ,,		
Ground nuts . .	13,000 ,,		
Henna . . .	1,000 ,,		
Sesame . . .	4,000 ,,		
Indigo . . .	1 ,,		
Others . . .	9,000 ,,		
Melons . . .	24,000 ,,		
Others similar . .	22,000 ,,		
		2,181,000 ,,	
Gardens—Oranges . . .	9,000 ,,		
Vineyards . . .	4,000 ,,		
Figs	2,000 ,,		
General . . .	13,000 ,,		
		28,000 ,,	
Grand total . . .		7,681,000 ,,	

158. **Duty of Water.**—In paragraphs 47, 69, and 87 we have given the duty of water at the heads of the canals and in drains, and we recapitulate them here.

Irrigation—Basin Tracts.

Sugar-cane in the south on pumps . .	60 cubic metres per acre per 24 hours.
Basin irrigation—maximum year . .	190 ,, ,, ,,
,, mean year . . .	125 ,, ,, ,,
,, minimum year . .	83 ,, ,, ,,

Irrigation—Perennial Tracts.

Upper Egypt—Summer:	cotton	36	cubic metres	per acre	per 24 hours.
„	sugar-cane	40	„	„	„
Flood:	millets	36	„	„	„
Winter:	wheat	16	„	„	„
Middle Egypt—Summer:	cotton	30	„	„	„
„	sugar-cane	36	„	„	„
Flood:	maize	30	„	„	„
Winter:	wheat	14	„	„	„
Lower Egypt—Summer:	cotton	24	„	„	„
„	rice	60	„	„	„
„	mean	30	„	„	„
Flood:	maize	24	„	„	„
Winter:	wheat	12	„	„	„

Drainage—Perennial Tracts.

Zone pumps for small areas	30	cubic metres	per acre	per 24 hours.
Public drains in the rice tracts	20	„	„	„
„ in the cotton tracts	10	„	„	„

159. **Cotton, Rice, and Winter Crops.**—The best dates for watering the different crops differ widely from one another in the opinion of sound agriculturists; and indeed in many places the ground water is so near the surface of the ground that actual practice must be widely different in different places. We first quote from a sound agriculturist:—

Upper Egypt.

"Cotton sowing begins after the middle of February, but is often delayed until May owing to the fact that so many cultivators grow cotton after harvesting the bean crop. The best time for sowing in Upper Egypt, *i.e.* on all the cultivable land south of Giza, is the end of February or the beginning of March, as there is little fear of frost or rain after that time. The cotton harvest commences about the middle of August and is finished by the end of October. The land receives the *taf el sharaki* watering before ploughing or a watering when the seed is sown. The next watering is not given until thirty to thirty-five days after this, and the one following is in from twenty to twenty-five days. The usual method of rotations will only permit subsequent waterings, until the flood arrives, at intervals of eighteen days, but it would be more advantageous were the intervals during June and July not permitted to be less than fifteen days. Up to the 15th July the cotton fields in Upper Egypt are usually in receipt of eight waterings, inclusive of the preparatory watering. Assuming that 350 cubic metres are taken at each watering and that the preparatory one requires 550 cubic metres, the amount of water taken up to the 15th July is 3000 cubic metres per acre. By shortening the intervals during June and July to fifteen days, one more watering would be obtained, which would give nine waterings in all before the flood and require a total of 3350 cubic metres before the flood. After flood rotations have been applied, the rate of watering

should be every fifteen days, giving four more waterings equal to 1400 cubic metres. The cotton crop thus receives 4400 cubic metres during the period of its cultivation. At least five more waterings are required by the clover which follows cotton until the end of the year.

Estimated Requirements for a Cotton Crop in Upper Egypt with respect to Times and Frequency of Watering.

				Cubic metres.
Watering before ploughing, middle of February Or at sowing, February 22				550
First watering after interval	30–35	days,	March 24–29	350
Second „ „	20–25	„	April 18	350
Third „ „	18	„	May 6	350
Fourth „ „	18	„	May 24	350
Fifth „ „	18	„	June 11	350
Sixth „ „	18	„	June 29	350
Seventh „ „	18	„	July 17	350
Eighth „ „	15	„	August 1	350
Ninth „ „	15	„	August 16	350
Tenth „ „	15	„	August 31	350
Eleventh „ „	15	„	September 15	350
			Total	4400 { per acre per crop.

LOWER EGYPT.

"Cotton sowing in Lower Egypt, by which we mean to indicate the whole of the cultivated area to the north of Cairo, commences at the end of February and may be continued until the beginning of May. It is, however, usual to sow, except in the northern parts of Gharbia and Behera, about the 12th March. The harvesting of the crop commences in the last week of August at the earliest and may be prolonged until the end of December or even into January in abnormally late years. It is usual to commence the first picking in the early part of September and to finish at the end of November or beginning of December. There are from one to four pickings. The crop generally follows clover, sown in the maize of the previous flood. The land receives one watering either for the ploughing or just before or after the seed is sown, according to the method adopted. It is not usual to give the next watering until thirty-five to forty days after sowing, and this is followed by another watering twenty-five to thirty days later. Taking the amount of water supplied at each watering as 350 cubic metres to the acre and the preparation watering at 550 cubic metres, as well as assuming that the rotations permit watering every eighteen days, the crop receives seven waterings previous to the 1st August, requiring 2650 cubic metres of water. Subsequent waterings will then be at the rate of one in fifteen days, so that until the middle of October the crop will receive five more waterings giving 1750 cubic metres. This gives 4400 cubic metres as the total requirements of the crop per acre. In the usual scheme of cultivation it is nearly always the case that clover is put in after cotton, and this necessitates at least two more waterings up to the end of the year.

Estimated Water Requirements for Cotton in Lower Egypt.

				Cubic metres.
Watering before ploughing, beginning of March Or at sowing				550
First watering after interval		35–40 days	April 16–21	350
Second	,,	25–30 ,,	May 11	350
Third	,,	18 ,,	May 29	350
Fourth	,,	18 ,,	June 16	350
Fifth	,,	18 ,,	July 4	350
Sixth	,,	18 ,,	July 22	350
Seventh	,,	15 ,,	August 6	350
Eighth	,,	15 ,,	August 21	350
Ninth	,,	15 ,,	September 5	350
Tenth	,,	15 ,,	September 20	350
Eleventh	,,	15 ,,	October 5	350
			Total	4400 { per acre per crop.

Rice when grown as a summer crop requires from sixteen to twenty waterings from the time of sowing until flood rotations are put on (about ninety-two days), or an average of once every five days. During the whole period of growth of a crop of 'Yapani' rice, averaging 110 days, nine waterings are necessary during May, seven in June, seven in July, and five in August; and, excluding the watering required for the preparation of the land (some 750 cubic metres per acre), the total water necessary for the crop is about 8000 cubic metres. A first watering of 750 cubic metres and then 110 days at 72 cubic metres per day $= 750 + (110 \times 72) = 8670$ cubic metres."

Mutwalli Bey, an experienced agriculturist in the Delta, sends us the following:—

"Irrigate wheat on the 15th January, 15th February, and 15th March. Cultivate clover on the 15th October. Irrigate lightly on the 5th November, then on the 15th December, then on the 15th January, and after that every twenty days. Rain never takes the place of irrigation in Kaliubia, Menufia, and Southern Gharbia. Rain is considered as a manure warming the soil and not as irrigation."

Another experienced agriculturist gives the dates of watering of the principal crops, as follows:—

"*Cotton.*—First watering at time of sowing; second watering, thirty to forty days after; third, twenty to twenty-five days after. Subsequent waterings according to rotations, *i.e.* every fifteen to twenty days.

From about the middle of August to the beginning of November the crop is only watered once every thirty days, *i.e.* a month before the first picking and immediately after each picking.

Cereals: Wheat and Barley.—First watering at time of sowing; second, watering, forty to forty-five days after; and third, when it comes into flower. (In Upper Egypt an extra watering is usually given in February.)

Maize or *Millet:* Summer.—First watering at time of sowing; second watering, twenty days after; and subsequent waterings every fifteen to twenty days, according to rotations.

Maize or *Millet:* Flood.—First watering (a heavy one) at time of watering the 'sharaki,' *i.e.* about the end of July; second watering, twenty days after; subsequent waterings, every fifteen to twenty days.

Rice: Summer.—Watering according to rotations; when possible, water is changed every two to three days during the first fortnight; then every four to eight days, according to available water supply for another six weeks; further waterings every eight to ten days.

Rice: Flood.—First month, the crop is watered every two to three days; second month, every four to six days; third month, every six to eight days.

Clover.—A heavy watering is given before sowing, and every fifteen to twenty days after. If left for seed, it is watered twice after the last cut."

It will be noted that the waterings of cotton recommended here are very few in number during the flood. Generally the ground is over-saturated at this time.

An experiment on late-sown cotton, very sparingly irrigated, was tried on the Bastara property in the north of the Delta by the Agricultural Department, and the following were the results :—

10 plots of $\frac{1}{2}$ an acre each, covering therefore 5 acres, were sown with cotton on the 16th May and irrigated immediately, and yielded between them 5350 rotls of unginned cotton, or 1070 rotls per acre. That means 3·4 kantars of ginned cotton per acre. Considering the class of soil and the economy of water, the yield was considered satisfactory. The land was recently reclaimed salted land with the water table about 80 centimetres below the surface of the ground. The drainage was pumped.

TABLE 260.—YIELD IN ROTLS OF UNGINNED COTTON.

Plot No.	North Plot.		South Plot.		Total.	Waterings.
	First Picking.	Second Picking.	First Picking.	Second Picking.		
1	282	240	262	197	981	45 days after watering, then every 30 days.
2	236	203	377	429	1245	40 ,, ,, ,, 25 ,,
3	315	245	342	267	1169	35 ,, ,, ,, 20 ,,
4	184	217	230	270	901	30 ,, ,, ,, 20 ,,
5	207	241	364	242	1054	25 ,, ,, ,, 15 ,,
Total	1224	1146	1575	1405	5350	

First year in cotton (following rice and clover).

Land with drains 25 metres apart. Each plot one-half acre in area.

The manager of the estate writes that of the three kinds of rice sown, it may be taken that the *Sultâni* rice takes 165 days to ripen, *Japan* rice 120 days, and *Sabâini* rice 90 days. Allowing 60 cubic metres per acre per day, we may say the first consumes 10,000 cubic metres, the second 7000, and the third 5000.

Mr Hood, of the Gharbia Company, informs us that on their properties which enjoy good surface drainage as well as subsoil drainage, the first watering of cotton after sowing is heavy and the surplus water is allowed to flow off freely; the next watering is very light; and the following also light, gradually increasing in quantity until the last watering in July with clear water is heavy and the surplus allowed to flow freely into the drains. When the red water comes in August, the first watering is very light, and the second slightly more, until the final watering before scattering the clover seed on the ground, which is very heavy and allowed to flow freely into the drains.

160. **Sugar-cane Cultivation.**—The following extracts are translations of a report kindly written for us by M. Naus Bey, the real sugar-cane expert of Upper Egypt:—

"The irrigation of sugar-cane is difficult on the perennial canals, as the long-timed rotations are quite unsuitable to the crop. Sugar-cane is better grown on pumps on the Nile. The centres to-day are Baliana, Naga Hammadi, Armant, Mataana, and Kom Ombo, where there are powerful pumping installations.

The three varieties of sugar cultivated in Egypt for fifty years came originally from Jamaica, and were imported by Ismail Pasha. They were well suited to Egypt; but in 1903 M. H. Naus imported 128 varieties from Java, Mauritius, Peru, Hawaii, Borneo, etc., of which some were hybrids. Of these No. 105 soon showed its superiority in growth and a sugar richness of 12 to 14 per cent. This No. 5 stands climatic changes, suits all soils, and is least affected by indifferent cultivation. It is red in colour, deep-rooted, fine and profuse; and yields 20 to 60 per cent. more than the other varieties. We have reaped 1150 kantars per acre the first year and 850 the second over large areas. This at $3\frac{1}{4}$ piastres per kantar would give us £37 per acre the first year and £27 the second. Ordinarily it gives 900 in the first year and 700 in the second. Its chemical changes, when cut, are unfortunately rapid, but this is guarded against by being quickly crushed. It is our best cane and grown on 20,000 acres.

The best rotations are two years cane, then a flood and winter crop, and the fourth year fallow. The fellahin in the fourth year take a winter crop, but this is poor agriculture. Any land, well levelled and not salted, in the Nile Valley, is suited to sugar-cane. The sandy clays are the best suited and the stiff clays the least, though the latter give better sugar proportions.

From the main canal leading from the pump, at every 100 metres, are led off secondary canals occupying with their banks 2·50 metres (see fig. 186).

The ridges are 90 centimetres apart and 35 centimetres high, and the beds are made into $\frac{1}{2}$-acre sizes by tertiary canals 21 metres apart at right angles to the secondary ones.

Between each pair of tertiaries is an *ados* (ridge).

The best time for planting is from the 15th February to the 10th April. The quantity of seed-cane per acre is 80 to 100 kantars. The canes are cut into three or four pieces each and laid in the furrows with the eyes at the sides. They are immediately covered with 7 or 8 centimetres of earth and irrigated. The first irrigations are ten-daily ones, and after five or six weeks the intervals should be fourteen-day ones. Between each irrigation the ground is lightly worked and thus cleared of weeds.

When the canes are from 50 to 60 centimetres high the manure is applied once or twice. No potash is needed, but a moderate amount of phosphate and liberal

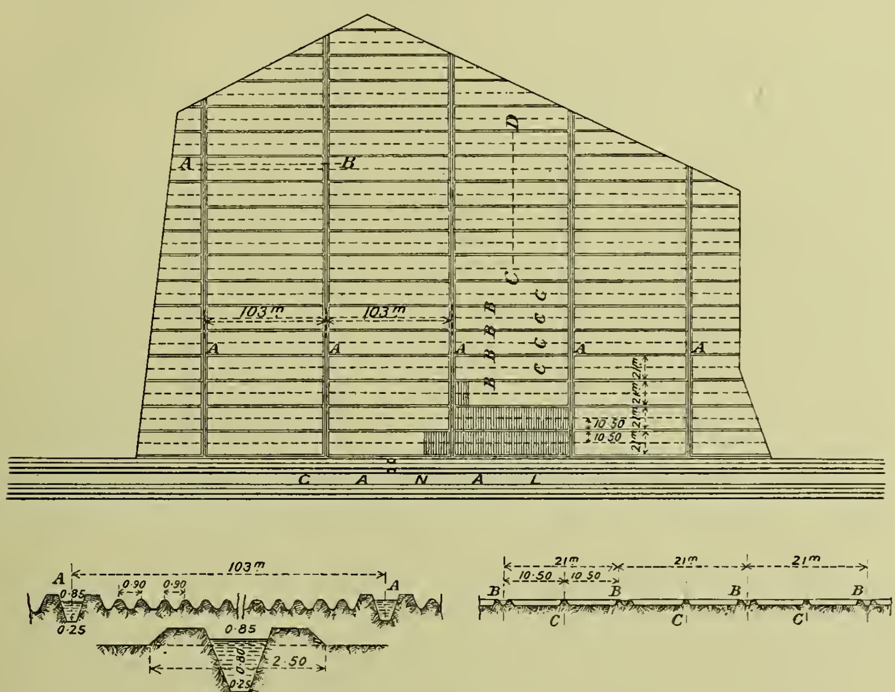


FIG. 186.—Sugar-cane Cultivation.

allowance of nitrate are required. Farm-yard manure is of course the best. Failing it, 150 kilos of sulphate or nitrate per acre should be given in two doses. Poudrette from 1000 to 1200 kilos per acre is good, but it encourages weeds and needs care. The manure should not exceed £2 to £2½ per acre. As the cane increases in size it should once or twice have the earth piled up to it. Once earthed nothing further is needed except steady watering.

The irrigations should be copious when the red water of the flood comes, and by heavy irrigation during the great heat the plants grow 2 centimetres per day. Red water at this time is as good as manure. We have found in Nile water at the end of August up to 1·8 grams of deposit per litre. This deposit contained lime 21 to 23 per cent., phosphoric acid 1·10 to 1·35, potash 1 to 1 20, and nitrogen ·95 to 1·25.

As each irrigation absorbs 550 cubic metres of water per acre, and cane receives 15 to 16 waterings, an acre of cane requires between 8250 and 8800 cubic metres of water.

Ratoon cane requires more frequent workings of the soil than first-year cane, but the waterings and manurings are the same. Third-year cane is not advisable.

We now give a balance-sheet of expenditure and receipts on a property of many thousands of acres:—

TABLE 261.—EXPENSES PER ACRE OF SUGAR-CANE CULTIVATION.

	First Year.	Second Year.
Supervision, European and Egyptian	£ ·700	£ ·700
Rent, including price of water	11·000	11·000
Preparing ground	1·200	·020
Price of seed-cane	3·650	...
Plantation	·950	·020
Manure	2·000	2·250
Irrigation (labour)	·900	·400
Maintenance of canals, etc.	·400	·080
Working up soil and earthing	·620	·360
Watchmen	·390	·320
Cutting and loading canes	1·400	1·100
General expenses	·750	·750
Total	£23·960	£17·000
Yield in canes	880 kantars	690 kantars
Value at $3\frac{1}{4}$ piastres per kantar	£28·600	£22·425 "

161. **Tobacco.**—We first quote from the Second edition:—

"It will have been noticed that no mention has been made anywhere of *tobacco.* Up to 1887 a light tax per acre was put on native-grown tobacco. It was raised in 1888, while in 1889 it stood at £50 per acre. The tobacco growers immediately imported skilled labourers from Macedonia, and so improved the quality of the tobacco they grew and cured that, though the tax was raised to £100 per acre in 1890, there was a considerable area put under tobacco. In 1891 tobacco growing was absolutely prohibited, and the people planted onions on the rich lands where they had previously grown tobacco. The tobacco revenue in 1897 was three times as great as it was in 1887, and as the Egyptians are inveterate tobacco smokers, they must have spent nearly £700,000 more on tobacco in 1897 than in 1887. The high price of tobacco is a very distinct hardship to the poor of this country, and in estimating the great advantages conferred on the country by the British Occupation this fact must always be remembered as counting on the opposite side. The absolute prohibition of so valuable and suitable a crop can never be considered as anything but a makeshift while there are sound financiers in the country.

TABLE 262.—TOBACCO REVENUE FOR EGYPT FROM 1887 TO 1897.

Year.	Revenue from Native Tobacco.	Octroi on Native Tobacco	Revenue on Imported Tobacco.	Total Revenue from all Sources.	Remarks.
	£	£	£	£	
1887	38,874	5411	289,050	333,335	
1888	10,040	...	332,516	342,556	Octroi on native tobacco abolished in 1888.
1889	90,575	...	441,443	532,018	
1890	37,994	...	1,237,787	1,275,781	Native tobacco was prohibited in June 1890. The reason the total revenue for this year was so high is that the merchants were allowed to clear all the tobacco they had in bond before the end of the year, as the duty was raised at the beginning of 1891.
1891	...	...	318,756	318,756	
1892	...	...	655,297	655,297	
1893	...	...	788,660	788,660	
1894	...	...	932,749	932,749	
1895	...	...	968,575	968,575	
1896	...	...	1,006,525	1,006,525	
1897	...	...	1,044,780	1,044,780	

The preceding table gives the tobacco revenue from 1887 to 1897. Since 1890 Turkish tobacco pays 20 piastres per kilogram and cut tobacco pays 25 piastres."

In the early years of the British Occupation, tobacco-growing was prohibited to enable the Government to add to its revenue by increased duties on imported tobacco which could be easily collected at the ports of entry. In those days the Finance Ministry had not a sufficiently reliable staff of Inspectors to see that large areas were not put under native tobacco without being recorded, and the Revenues of Egypt barely sufficed to meet the Expenditure. To-day the Finance Ministry disposes of a large number of absolutely reliable Inspectors, and the annual Revenue is £2,000,000 in excess of the Expenditure. When we consider that the sandy soil of the Nile berms, islands, and cataracts is eminently suited to the growth of tobacco, and that the country badly needs to widen the field of its agricultural products, the day has surely come for removing the prohibition of the cultivation of so profitable a crop. The moderate quantity of lime in the Egyptian soil is in favour of the production of a tobacco of good quality.

162. **The Date Palm.**—Mr G. L. Bailey, the manager of the large date palm estate near the Pyramids known as the Pyramids Estate, has kindly supplied us with the following information about date culture, which might very profitably be extended in Egypt. Egypt already possesses many varieties of dates, and date culture has existed here from time immemorial; but we produce none of the valuable *Diglet el Nur* variety, though the Pyramids Estate has introduced young plants from Tunis. Mr Bailey refers us for information to a pamphlet by Mr F. Fletcher, Deputy Director of Agriculture in Bombay, in the *Agricultural Ledger*, 1906, No. 1, entitled

"*Phœnix dactylifera*" (the date palm), Part I., published in Calcutta at the office of the Superintendent, Government Printing, India, 1906 (price, threepence). This is an excellent pamphlet and as cheap as it is good, and all who begin date culture should procure it.

Mr Bailey adds the following information for Egypt:—

"The best time for planting in Egypt is when the soil has warmed a little.

In Lower Egypt: 15th March to 15th June,
In Upper Egypt: 15th February to 15th May.

Planting is also done on the rise of the Nile from about 15th August to 15th September, but is not so successful as the spring planting.

Our trees are planted 7 metres apart, or 87 to the acre. We should, therefore, according to Mr Fletcher, require $\frac{87}{70} \times 6300$, or 7800 cubic metres of water per acre per annum, if our conditions were those of the Algerian Sahara. But, generally speaking, the water table of Egypt, and especially of Lower Egypt, is far higher than that of the Sahara, and our requirements may be reduced by one-fourth for Upper Egypt and one-third for Lower Egypt. The amount of water required per acre per annum is therefore reduced to 5890 cubic metres for Upper Egypt and 5200 for Lower Egypt.

Of the above, three-quarters would have to be distributed during the hot months, *i.e.* from May to September. The maximum duty of water per acre per twenty-four hours therefore works out to $\frac{5890 \times \cdot 75}{5 \times 30} = 30$ cubic metres for Upper Egypt, and $\frac{5200 \times \cdot 75}{5 \times 30} = 26$ cubic metres for Lower Egypt.

This is for the light sandy soils on the edge of the desert. For soils more retentive of moisture the duty would be less.

On our lands near the Pyramids the water table never falls below 3·50 metres and the figures given above are confirmed by practical experience."

The Agricultural Department might certainly import the *Diglet el Nur* date palms from Algeria and Tunis and two or three of the best varieties from the Persian Gulf. Since the valuable *Diglet el Nur* date of Algeria is named after the Tigris (*Digla*), it is possible that the plant was originally introduced from Basra. Indeed, it is more than likely that the delicious *Hellawi* date of the Gulf would develop naturally into some form of *Diglet el Nur* in the dry climate of Egypt.

163. **Dates of Sowing and Harvesting**.—We give a table showing dates of sowing and harvesting:—

[Table

TABLE 263.—DATES OF SOWING AND HARVESTING OF EGYPTIAN CROPS.

Crop.	Dates of Sowing.		Dates of Harvesting.	
	Lower Egypt.	Upper Egypt.	Lower Egypt.	Upper Egypt.
Cotton	March to April	February 20 to April 5	Sept. 15 to Nov.	Sept. to Nov. 15
Cotton (Basins)	...	February 15 to March 15	...	Aug. 10 to Sept. 15
Maize (Flood) — American, etc.	End July to August 20	End July to August 20	Nov. 20 to Dec. 20	Nov. 15 to Dec.
Maize (Flood) — Sabâini	August	August	End Oct. to Nov.	End Oct. to Nov.
Millet — Summer	...	March 15 to April 20	...	End July to Aug. 20
Millet — Flood	End July to August 20	End July to August 20	Nov. 20 to Dec. 15	Nov. 20 to Dec. 15
Wheat — Perennial	Nov. 10 to Dec. 20	Nov. to Dec. 20	May	April 20 to May 20
Wheat — Basins	...	Oct. 15 to Dec. 20	...	End March to April
Barley — Perennial	Nov. 10 to Dec. 20	Nov. 10 to Dec. 15	April 20 to May 15	April 10 to May 10
Barley — Basins	...	Oct. 15 to Dec. 15	...	March 20 to April 20
Rice — Summer	May to June	...	Sept. 15 to Nov.	...
Rice — Flood	End July to August	End July to August	End Oct. to beginning Dec.	End Oct. to Dec. 15
Sugar-cane	March to April 20	End February to April 20	November to March	End October to March
Beans — Perennial	Nov. to beginning Dec.	Nov. to beginning Dec.	April to May 20	April
Beans — Basins	...	Oct. 15 to beginning Dec.	...	March to April 15
Berseem (Clover)	Sept. 15 to Nov. 20	Sept. to Nov. 20	Nov. to May "green" June "for seed"	Nov. to May "green" June "for seed"
Lucerne	March to April	March to April	1st cutting in May to June, subsequent cutting every 35 to 40 days	
Lentils (Basins)	...	Oct. 20 to Nov.	...	March 15 to April 10
Vetches (Basins)	...	Oct. 20 to Nov.	...	Feb. "one cutting green" March to April "for seed"
Fenugreek	November	Oct. 15 to Nov.	April	March 15 to April
Lupins	October 15 to November	Oct. 15 to Nov.	April	April
Sesame	June to July 10	June	October	October
Earth Nuts	March 15 to April	March 15 to April	Nov. to Dec. 15	Oct. 15 to Nov.
Henna	March to April 10	...	September to December	...
Flax	Oct. to beginning Dec.	October to November	March to April	March to April
Onions	(Beheri) bulbs planted in March	Main crop: seed sown Aug. 15 to Sept. Transplanted Oct. 10 to Nov.	July	March 10 to April 15
Melons — Summer	2nd, March to April	1st, November 2nd, March to April	July to August	End May to August
Melons — Flood	July to August	July to August	October to November	October to November
Dates	...	...	Sept. to beginning Nov.	August to October

164. **Cost of Raising and Yield of Crops, 1912.**—We give four tables for the above prepared for us by officials of the Agricultural Department by the kind permission of Mr G. Dudgeon, the Director-General.

TABLE 264.—COST OF RAISING CROPS AND YIELD PER ACRE OF GOOD LAND IN UPPER EGYPT, 1912.

Name of Crop.	Cost of Raising.							Value of Yield.					Net Profit.	Remarks.
	Ploughing and Sowing.	Seed.	Irrigation.	Weeding and Reaping.	Manure.	Carriage to Market.	Total.	Yield of Grain and Seed. Quantity.	Yield of Grain and Seed. Value.	Yield of Straw or Fibre. Quantity.	Yield of Straw or Fibre. Value.	Total.		
	£	£	£	£	£	£	£		£		£	£	£	
Sugar-cane	1·50	3·00	2·00	1·50	2·00	...	10·00	...	...	600	24·00	24·00	14·00	
Cotton .	1·20	·30	1·50	1·50	1·00	·20	5·70	...	...	7*	21·00	21·00	15·30	
Wheat .	·40	·60	·20	·50	1·00	...	2·70	7	7·00	8	2·80	9·80	7·10	
Indian corn	·30	·20	·50	·50	1·00	...	2·50	8	6·40	...	·50	6·90	4·40	
Millet .	·30	·20	·50	·50	1·00	...	2·50	10	6·00	...	·50	6·50	4·00	
Wheat .	·05	·60	...	·50	...	...	1·15	6	6·60	8	1·50	8·10	6·95	Basin.
Beans .	·05	·45	...	·40	...	...	·90	6	4·80	8	1·00	5·80	4·80	Basin.
Clover .	·05	·45	...	...	...	...	·50	...	...	...	...	5·00	4·50	Basin.

TABLE 265.—COST OF RAISING CROPS AND YIELD PER ACRE IN THE GOOD LANDS IN THE SOUTHERN HALF OF LOWER EGYPT, 1912.

Name of Crop.	Ploughing and Sowing.	Seed.	Irrigation.	Weeding and Reaping.	Manure.	Carriage to Market.	Total.	Grain Quantity.	Grain Value.	Straw Quantity.	Straw Value.	Total.	Net Profit.	Remarks.
Cotton .	1·20	·30	2·50	1·80	1·50	·20	7·50	...	...	6·50	22·75	22·75	15·25	
Sugar-cane	1·20	3·00	3·00	1·80	1·50	...	10·50	...	...	...	40·00	40·00	29·50	
Indian corn	·40	·20	...	1·00	1·50	...	3·10	10	8·00	...	·20	8·20	5·10	
Wheat .	·40	·50	·50	1·00	1·00	...	3·40	7	7·00	·10	2·25	9·25	5·85	
Beans .	·40	·50	·50	1·00	1·00	...	3·40	6	4·80	...	1·00	5·80	2·40	
Barley .	Not cultivated in best land in southern half of Lower Egypt.													
Clover .	...	·60	2·00	...	...	...	2·60	...	...	...	...	11·00	8·40	Irrigated.
Clover .	...	·60	...	...	...	...	·60	...	...	...	...	5·00	4·40	Not irrigated.

* *Mit afifi* cotton.

TABLE 266.—COST OF RAISING CROPS AND YIELD PER ACRE OF SUPERIOR LAND IN THE NORTHERN HALF OF LOWER EGYPT, 1912.

Name of Crop.	Cost of Raising.							Value of Yield.						
	Ploughing and Sowing.	Seed.	Irrigation.	Weeding and Reaping.	Manure.	Carriage to Market.	Total.	Yield of Grain and Seed.		Yield of Straw or Fibre.		Total.	Net Profit per acre.	Remarks.
								Quantity.	Value.	Quantity.	Value.			
	£	£	£	£	£	£	£		£		£	£	£	
Cotton	1·20	·30	1·00	1·60	1·00	·20	5·30	...	...	5*	17·50	17·50	12·20	
Sultâni rice	...	...	...	...	...	...	...	...	...	...	7·00	7·00	3·50	
Flood rice	...	...	...	...	...	...	...	...	...	...	3·00	3·00	2·00	
Indian corn	·40	·20	...	·80	1·00	...	2·40	7	5·60	...	·20	5·80	3·40	
Vegetables														
Wheat	·40	·50	·20	1·00	1·00	...	3·10	5	5·00	...	1·00	6·00	2·90	
Barley	·40	·30	·20	1·00	·50	...	2·40	8	4·80	...	1·00	5·80	3·40	Would not generally be grown in good land.
Clover	...	·60	1·00	...	...	...	1·60	...	...	...	...	8·00	6·40	

TABLE 267.—COST OF RAISING CROPS AND YIELD PER ACRE OF INFERIOR LAND IN THE NORTHERN HALF OF LOWER EGYPT, 1912.

Name of Crop.	Ploughing and Sowing.	Seed.	Irrigation.	Weeding and Reaping.	Manure.	Carriage to Market.	Total.	Grain Quantity.	Grain Value.	Straw Quantity.	Straw Value.	Total.	Net Profit per acre.	Remarks.
Cotton	·60	·40	1·00	1·00	...	·20	3·20	...	...	3*	9·00	9·00	5·80	
Sultâni rice	...	...	...	...	...	...	...	...	...	...	...	6·00	3·50	
Flood rice	...	...	...	...	...	...	...	...	...	...	...	3·00	2·00	
Indian corn	·40	·20	...	90	...	...	1·00	3	2·40	...	·20	2·60	1·50	
Wheat	·30	·50	...	50	...	...	1·30	2 50	2·50	...	·30	2·80	1·50	
Barley	·40	·30	...	40	...	...	1·10	4·00	2·40	...	·30	2·70	1·60	
Clover	...	·50	...	...	...	...	·50	...	...	...		4·00	3·50	

* *Mit afifi* cotton.

165. **Areas protected by Pumps and Sakias.**—The following table prepared by Mr Dupuis, gives the sizes of pumps permitted by the Government on the canals, and the equivalent number of single sakias:—

TABLE 268.—PUMP AND SAKIA DISCHARGES AND THE AREAS PROTECTED BY MACHINES OF VARIOUS SIZES.

Machines.	Approximate Discharge per 24 hours.	Equivalent Number of Single Sakias.	Area watered per day, allowing 350 cubic metres per acre per 24 hours.	Area irrigated in 6 days, allowing 350 cubic metres per acre per 24 hours.	Area protected in 6 days, assuming 40 per cent. of the Area under Perennial Crops.	Diameter of Pump Culvert not to exceed
	Cubic metres.	No.	Acres.	Acres.	Acres.	Linear metres.
Single sakia	300	1	0·8	4·8	12	0·10
Double sakia	600	2	1·7	10	25	0·15
4-inch pump (suction pipe) .	1,248	4	3·5	21	53	0·20
4-inch pump (discharge pipe) .	2,304	7	6	36	90	0·25
5-inch pump (suction pipe) .	2,366	8	6·7	40	100	0·25
5-inch pump (discharge pipe) .	3,600	12	10	60	150	0·30
6-inch pump (suction pipe) .	3,408	11	10	60	145	0·30
6-inch pump (discharge pipe) .	5,184	17	15	90	225	0·35
7-inch pump (suction pipe) .	4,815	16	14	84	205	0·35
7-inch pump (discharge pipe) .	7,056	23	20	120	300	0·40
8-inch pump (suction pipe) .	6,528	22	19	114	280	0·40
8-inch pump (discharge pipe) .	9,216	30	26	156	390	0·45
10-inch pump (suction pipe) .	10,200	34	29	174	435	0·45
10-inch pump (discharge pipe) .	14,400	48	41	246	615	0·50

12-inch pump (suction pipe) .	14,688	49	42	252	628	0·50
12-inch pump (discharge pipe) .	20,736	69	59	359	897	0·55
14-inch pump (suction pipe) .	19,992	67	37	342	855	0·55
14-inch pump (discharge pipe) .	28,224	94	85	510	1,275	0·60
15-inch pump (suction pipe) .	22,994	76	65	390	980	0·60
15-inch pump (discharge pipe) .	32,400	108	92	552	1,380	0·65
16-inch pump (suction pipe) .	27,648	92	79	474	1,183	0·65
16-inch pump (discharge pipe) .	36,864	122	105	630	1,575	0 70
18-inch pump (suction pipe) .	34,992	117	100	600	1,495	0·70
18-inch pump (discharge pipe) .	46,656	155	133	798	1,995	0·75
20-inch pump (suction pipe) .	43,200	144	123	738	1,848	0·80
20-inch pump (discharge pipe) .	57,600	192	164	984	2,460	0·95
24-inch pump (suction pipe) .	6,2208	207	177	1·062	2,660	1·00
24-inch pump (discharge pipe) .	8,2944	276	237	1·422	3,555	1·15
30-inch pump (suction pipe) .	97,200	324	277	1·662	4,155	1·25
30-inch pump (discharge pipe) .	129,600	432	370	2·220	5,550	1·45

The above pumps, where diameters of discharge pipes are given, apply to the new type of helical pumps having their suction end larger than their discharge; and where diameters of suction pipes are given, apply to the old type centrifugal pumps, having their suction and discharge ends of equal diameter.

166. **The Dates of Sharaki Irrigation.**—The Sharaki decree is the decree prohibiting the irrigation of the ground preparatory to sowing the Indian corn crop, until permission is given by the Irrigation Department.

Table 189, page 414, gives the dates from 1902 to 1912 on which permission was given to irrigate sharaki.

On pages 412 and 413 we have advocated the delaying the date of sharaki irrigation, and on page 414 we have noted with satisfaction the passing of a Khedivial decree putting on the date of permission to irrigate to the 1st August if necessary. In 1913 the date was the 27th July.

167. **Cotton Worm and Boll Worm.**—The following has been kindly written for us by Mr G. Dudgeon, Director-General of the Agricultural Department:—

"A factor which serves to determine the success of agricultural operations in Egypt, and one which is only second in importance to the water supply itself, is the prevalence of the attacks of insect pests. All the energy which has been put into the cultivation and careful treatment of a crop may be nullified by an unavoidable visitation of destructive insects.

The more important pests which occur in Egypt annually with more or less severity are as follows:—

On Cotton.—Two kinds of cotton worms (*Prodenia litura* and *Laphygma exigua*), feeding on the leaves, flowers, and buds; two kinds of boll worms (*Earias insulana* and *Gelechia gossypiella*), feeding on the inside of the bolls, buds, and, in the case of the first, on the interior of the terminal shoots: in the case of the second, on the seeds; two kinds of cut-worms (*Agrotis ypsilon* and *Euxoa spinifera*), feeding upon the sprouting cotton seedlings; and one kind of aphis (*Aphis sorghi*), usually called 'Nadwat el assalia,' feeding on the young shoots and leaves.

On Wheat and Barley.—Both the cut-worms mentioned above.

On Clover and Beans.—Both the cotton worms and cut-worms mentioned previously.

On Maize.—Both the cotton worms and cut-worms mentioned and two stem borers (*Sesamia cretica* and *Leucania Loreyi*).

On Sugar-cane.—The two stem borers mentioned above and another (*Chilo simplex*) which is not so common.

It is only necessary in this account to refer to the more important among those mentioned, and, as those which have had the greatest attention paid to them during recent years are the the cotton worm (*P. litura*) and the boll worm (*E. insulana*), a short account is given here of each.

The name 'cotton worm' is most generally applied in Egypt to the caterpillar of a moth named *Prodenia litura*, Fabricius. This insect has a great range of distribution in the world's fertile regions: it occurs in Turkey and Crete, in Europe; throughout the temperate and tropical parts of Africa and Asia; in Eastern and Southern Australia and the Pacific Islands. Although extending into many places where cotton is cultivated, it is remarkable that the insect has never been recorded as attacking cotton, except in Egypt. It is quite clear that the cotton plant is not its natural food, and that it is only the force of circumstances which has compelled it to adapt itself to feeding upon the plant in this country. Even in Egypt it will

be constantly observed that if more palatable foods, such as clover or maize, are available, cotton worms will infest these crops by preference.

The cotton worm was first recognised as a pest upon cotton plants in Egypt in 1877, when MM. de Vecchi and Amici drew the attention of His Excellency Ragheb Pasha, Minister of Agriculture and Commerce, to the destruction caused by it to the cotton fields at Shubra. Previous to this time it had doubtless occurred commonly on clover and other plants, though there is even reason to believe that it may have occasionally caused the local destruction of cotton fields.

The insects undergo four distinct changes during the period of their existence, of which the first is the egg, the second the caterpillar or worm, the third the chrysalis or pupa, and the fourth the moth. The moths lay their eggs, of which there are on an average 600 deposited by each female, in masses, covered with a brownish down which protects them from the action of the sun and moisture. The egg masses are usually deposited upon the under surface of the leaves upon which the young worms feed. The worms feed for the first four or five days upon the leaves upon which the egg masses had been placed, after which they distribute themselves over the plants and feed upon the leaves, buds, and flowers wherever found. When full grown the worm is about 3 centimetres in length and attains this size in from eighteen to thirty days from the time when it existed as a newly deposited egg. The variation in the time of development is in accordance with the time of year when the particular generations occur. When full grown the worm enters the ground in order to undergo the next change, and forms a mud cell in which to become a chrysalis. It remains in this state from about seven to twenty days, or perhaps longer, when it develops into a moth and makes its way to the surface in order that its wings may become properly expanded and hardened to enable it to fly, and, if a female, to deposit another mass of eggs which will serve to produce the next generation of worms.

There are at least six generations of the insect in each year, the first two of which inhabit the clover crops and multiply enormously therein. The duration of each generation is probably from twenty-four to seventy days according to temperature. Towards the end of each year, owing to the scarcity of food and the more severe climatic conditions, only a few moths emerge and are capable of depositing their eggs in the fields of young clover. Throughout the early part of the year when the nights are cold and the worms suffer much from exposure the numbers are still further reduced so that a diminished number of individuals emerge as moths at the end of February to lay their eggs. From this time forwards the climatic conditions usually improve and the increase goes on at an extremely fast rate. From an example of the possible multiplication of individuals in three generations (eliminating the reducing factor, which fortunately exists, and which is represented by the action of predatory insects, birds, and reptiles) it may readily be seen what enormous proportions may be attained in about eighty days.

1 female lays 600 eggs in clover on the 20th February, out of which an equal number of males and females are produced as moths about the 3rd April. There are therefore 300 females.

300 females lay 600 eggs each, say 180,000, out of which emerge equal numbers of males and females about the 5th May. There are now 90,000 females.

90,000 females lay 600 eggs each upon clover and cotton, or 54,000,000 eggs, which produce this number of worms to feed upon these crops on about the 11th May.

From this it will be seen that the progeny of one female moth may be increased to 54,000,000 in a period of eighty days, if the reducing factor be entirely abolished. That such a rate of increase never actually occurs is mainly on account of the existence of so many natural enemies which exist and which destroy large numbers. The value of these important allies in the pest war which is constantly being waged by the agriculturist has scarcely been recognised in Egypt hitherto, but the extent of their control is now being carefully investigated by the scientific staff of the Department of Agriculture. In the *Journal of the Agricultural Department*, vol. ii. part 1, a number of the insects destructive to cotton worms have been figured. Among these a beetle (*Calosoma imbricata*) feeds voraciously on the worms in all stages; a rover beetle (*Paederus sp.*) and the larval form of a lace-wing fly (*Chrysopa vulgaris*) devour the eggs; two species of wasps (*Eumenes maxillosa* and *Polistes gallicus*) store their cells with the worms, either alive or in a masticated condition; a Techinid fly and a Braconid ichneumon deposit their eggs, so that their grubs may enter the intestines of the cotton worms and destroy the host, and several less important insects utilise the worms as food. Among diseases, the protozoan disease (*Microsporidium polyedricum*) which was so prevalent in 1912 is probably more effective than anything else; the development of the third brood of cotton worms in the cotton was completely prevented by the virulence which this disease assumed in 1912. Insectivorous birds, lizards, and frogs devour innumerable quantities of worms and require to be protected from destruction.

In addition to the work carried on by the natural enemies mentioned above, other agencies are at work which assist in a lesser degree in controlling the pest. Among these may be mentioned the disturbance of the soil by cultivation or irrigation, and the collection of the egg masses in the early broods by the people themselves. It should be noted, however, in the latter connection that the effectiveness of the operation is in proportion to the earliness with which it is carried out.

Before leaving the subject of the cotton worm it must be remarked that the damage done by an attack is very frequently over-estimated. This is due to the apparent severity of an attack at any period. When, however, the attack is early and apparently severe, very little damage is done in comparison with a much less apparently severe attack occurring in August or September. In many cases the loss attributed to cotton worm is more justly due to other causes.

Although less conspicuous than the cotton worm, owing to its cryptic methods of attack, the boll worm is generally acknowledged by entomologists in Egypt to cause more destruction to the cotton plant annually than the cotton worm. The more important of the two Egyptian boll worms is that called *Earias insulana*, Boisduval, which occurs throughout North Africa, India, and Ceylon, and extends to Queensland in North Australia.

This insect, similarly to the cotton worm, undergoes four well-marked changes in each generation. The egg is, however, deposited singly upon the leaf axils of cotton and Hibiscus, and the young worm tunnels into the terminal shoots, afterwards living in the interior of buds or bolls. The chrysalis is formed in a silk cocoon on the outside of the boll, and the moth flies considerable distances in order to deposit her eggs. At least five generations occur during the year, diminishing in numbers during the winter and attaining their greatest numbers in the late autumn.

The boll worm was observed in Egyptian cotton plants some years previous to the cotton worm and has been known as a cotton pest in India for a number of years.

Theoretically the insect could be easily controlled in Egypt by completely destroying the food plants during the winter months. As these food plants are limited to cotton and the few species of the allied genus Hibiscus, no inconvenience would be occasioned by their rigorous destruction, none of these plants yielding crops during the winter. There is, however, a bad practice carried on in some districts in the north by which cotton crops are allowed to remain in the ground for two years or more, and it has been clearly demonstrated that these localities form breeding-grounds from which large numbers of boll worm moths are produced and are distributed over the districts to the south by means of the prevailing north winds.

Boll worms are not destroyed in large numbers by insectivorous birds or lizards, as their method of feeding inside the boll or stem protects them. They are, however, parasitised by several small Braconids, the individuals of which enter the bolls and deposit eggs in the bodies of the boll worms. The grubs emerging from these eggs infest the intestines and eventually destroy the boll worm. Some interesting species of parasites of this class have been discovered in India, and by means of propagating them and introducing them into badly attacked localities an appreciable gain has been obtained in the crop. Some of these insects have been introduced into Egypt by the Department of Agriculture, and investigation by the entomological staff of the Department has brought to light some indigenous insects with the same habits as the Indian ones.

Having briefly dealt with the two most important cotton pests, it must only be remarked that the cut-worms sometimes do great damage to the young wheat in Upper Egypt and that the cotton aphis sometimes destroys patches of cotton and maize. The borers which occur on sugar-cane never appear in sufficient numbers to materially affect that crop, which is notably free from disease in Egypt in comparison with other countries where it is grown."

168. **Weights and Measures.**—We quote from the Second edition, brought up to date:—

The following table explains all *local weights and measures* used in this book :—

TABLE 268A.—WEIGHTS AND MEASURES.

Comparison between French and English.

1 metre	= 3·28084	feet	. 1 foot	= ·304800	metre.
1 square metre	= 10·7639	square feet	. 1 square foot	= ·092903	square metre.
1 cubic metre	= 35·3148	cubic feet	. 1 cubic foot	= ·028317	cubic metre.
,,	= 219·975	gallons	. 1 gallon	= ·004546	,,
,,	= 27·497	bushels	. 1 bushel	= ·036368	,,

1 kilogram	= 2·20462	lbs.
1 lb.	= ·453592	kilogram.
1 French H.P.	= ·986337	English H.P.
1 English H.P.	= 1·01385	French H.P.
1 acre	= 4046·85	square metres.
5 miles	= 8	kilometres (approximately).

Egyptian.

Length.—	1 pic (architects')	= ·75 metre.
	1 pic (Nile gauge)	= ·54 ,,
	1 kassaba	= 3·55 metres.
Square.—	1 feddan (acre)	= 4200·83 square metres.
	1 kirat	= 175·0347 ,,
	1 kassaba square	= 12·6025 ,,
Cube.—	1 kassaba cube	= 44·7389 cubic metres.
Dry measure.—	1 ardeb	= ·198 cubic metres = 5·4474 bushels.
	1 kêla	= $\frac{1}{12}$ ardeb = ·0165 cubic metre.
Weight.—	1 rotl	= ·44928 kilogram = ·99049 lb.
	1 oke	= 1·248 ,, = 2·7514 ,,
	1 kantar	= 44·928 ,, = 99·049 ,,
Money.—	£1 Egyptian	= 100 piastres = 1000 milliemes = £1 0s. 6d.
	£1 English	= 97½ ,, = 975 ,,

Liquids are weighed in Egypt.

The English acre, pound and £ are very nearly the same as the Egyptian acre (feddan), the Egyptian pound (rotl), and the Egyptian £ (known in the country as the guinea).

In this book the Egyptian acre and the Egyptian £ have been invariably employed.

1 kantar of cotton in seed weighs about 315 rotls, of which the cotton weighs about 100 rotls, and the remaining 215 rotls make about $\frac{3}{4}$ of an ardeb of cotton seed. The ginning outturn varies with different varieties of cotton.

1 kantar of ginned cotton weighs 100 rotls = 99·049 lbs.
1000 ardebs of cotton seed = 118 tons.
100 ,, of wheat = 68 quarters.
100 ,, of beans = 66 ,,
1 dariba of rice before husking = 18 kantars.

The produce of the fields is always spoken of in ardebs (1 ardeb = 5·45 bushels), while seed corn is always spoken of in kêlas (1 ardeb = 12 kêlas).

Wheat, straw, cotton stalk, etc., are always given in "himls" or camel-loads of between 500 and 600 lbs.

1 *himl* for purposes of commerce = 200 okes = 545 lbs.

169. **Improvement in Quality and Yield of Cotton.**—Three highly interesting papers on this subject were read before the delegates of the Cotton Association in December 1912. We have before us epitomes of these papers: the first by Mr G. C. Dudgeon, the second by Mr W. Laurence Balls, and the third by Dr Lewis Gough. They are all well worth studying, and we regret that we can only find room for the first.

"*Seed Distribution.*

Almost exactly two years ago, I was charged with the formation of a Department of Agriculture in Egypt, and as soon as I had got together a staff sufficient to

form the nucleus of the same, I selected what appeared to be the most important agricultural questions in the country and gave them particular attention.

The most prominent agricultural product being cotton, the best means of preventing the deterioration of the quality as well as of the quantity per acre were among the first matters examined. Being fortunately possessed of exceptional experience in cotton growing in all the most important producing countries in the world, I was enabled to take up both these questions promptly, and to avoid the many pitfalls which anyone without these advantages might have stumbled into.

With a view to the improvement of quality, for instance, it was constantly urged that the primary, if not the only means, to attain this end, was by the introduction of new varieties. Many of the advocates of this seem to have had no very clear idea of how to proceed, or what might be the result of relying entirely upon such means for improvement.

It is not a difficult matter, as I have no doubt Mr Balls will tell you in his lecture upon plant breeding, to produce new varieties of cotton, but to obtain one which shall be suitable for cultivation in a large part of the country and which at the same time shall meet the exact requirements of the spinning industry, is a work which necessitates a great amount of patient study, and one which cannot be completed within a short time.

Most of the advocates for the introduction of new cottons appear to have considered that a variety yielding longer, finer, and more silky lint was all that was required to satisfy the trade; but experience in other parts of the world, as well as in Egypt itself, has shown that the demand is small for cotton in which these qualities are developed beyond a certain limit. What we understand is at present most necessary is a purification of the existing types of cotton, the quality of which has been steadily declining. It was to stem the tide of deterioration that the Department adopted its seed distribution project as the initial step in a scheme of cotton improvement.

Some of the causes of the deterioration may be referred to here as having an important bearing upon the scheme. There may be said to be at present in Egypt about seven or eight well-marked types of cotton, the plants of which are often found growing in adjoining fields and the cotton from which is ginned in the same machines. Both these are causes of deterioration from the typical form: in the first case through hybridisation from approximation, and in the second through the mixing of the seed in the gins. Apart from these influences upon the purity of the seed, which it is hardly possible to avoid entirely, a system had grown up in Egypt whereby the smaller cultivators, especially, were being supplied with mixed and inferior seed by the small seed merchants who were also money-lenders, and upon whom the cultivators had become completely dependent.

This last is doubtless a strong fundamental reason for the deterioration of the quality. It was ascertained that the small cultivator obtained his seed on credit, but that the rate of interest charged him by the seed merchant, from the time of sowing until he gathered his crop, brought up the price of the seed to a very high figure. As it was to the seed merchant's advantage, unless he had arranged to take a proportion of the cotton crop in lieu of payment, to supply the least expensive seed, the cultivator was usually the sufferer with respect to the quality.

It was also ascertained that the small cultivator could not afford to pay cash for

his seed and that unless credit was given by Government it would be impossible to remedy the state which existed.

Taking these facts into consideration, the Department of Agriculture proposed that Government should take over the supply of seed to this class of people and that a distribution should be made to them upon credit; the cost of the seed, without interest, being recovered in the following November of each year.

Although the Department was only formed upon the 1st January 1911, I urged that an attempt at such distribution should be made, if only upon a small scale, in that year, in order that we should be in a better position to bring the scheme into full working order in the spring of 1912. The Government thereupon consented that we should commence operations in one province in Lower Egypt and placed at the disposal of the Department a sufficient credit with which to buy seed. By the time this matter had been arranged, most of the cultivators had provided themselves with seed for their requirements, but in spite of this the Department disposed of 1500 ardebs in the one province of Sharkia. Everything worked very satisfactorily, and the whole of the cost of this seed was recovered by the Department of Direct Taxes with the November tax instalment. The distribution in 1912 increased to 40,000 ardebs *; and it is expected that for 1913 the demand will exceed twice this amount, as the Government seed distribution has become extremely popular, in spite of the attempts on the part of the small seed merchants and others to decry the efforts of the Department of Agriculture, even to the extent of adopting many underhand devices.

It will be asked, no doubt, from where the Department of Agriculture has obtained sufficient seed of good quality to supply the extensive demands which it has to meet, and in reply it must be admitted that, without the assistance of the largest and most reliable ginners in the country, the distribution could scarcely have reached the dimensions it has in so short a period. The thanks of the small cultivator are then largely due to the gentlemen who control the ginneries, who by their assistance have enabled the cultivator to procure a good quality of seed at a fair price in place of a bad one at a high price.

Although this supply of seed makes for the improvement of the cotton grown by a large majority of the cultivators in Egypt, it is only a portion of the scheme of cotton improvement, the full details of which can scarcely be entered into here, but will be briefly sketched.

For some years the seed produced upon the State Domains lands has been regarded as some of the best and purest in the country. The distribution of the surplus seed grown on these lands has, until this year, been entirely entrusted to the Khedivial Agricultural Society, who supplied it to the most careful cultivators in the country at a fair price. An endeavour was made to stipulate when supplying such seed that the resultant seed crops should be obtained by the Society for redistribution, but the difficulties which were met with prevented this scheme being carried out.

A modified plan is being adopted now by the Department of Agriculture, whereby arrangements have been made with the most important and careful ginners in the country that 50 per cent. of the seed obtained from the first pickings of cotton bought by them from those cultivators who planted Domains seed, shall be put at the option of the Department of Agriculture for redistribution. The cultivators who purchased the Domains seed from the Department were only

* About 218,000 bushels.

permitted to do so on signing a contract by which they agreed that the officials of the Department might inspect their fields at any time, and by which they promised to notify the Department the name of the merchant or ginner to whom they sold their cotton crop. It is hoped that in this way the improvement in the quality of cotton will be effected from the top as well as from the bottom, in the manner previously referred to.

Other portions of the scheme are in connection with the production of pure and regular types of cottons by means of the Mendelian process of breeding at the Department's experimental farms, which are under the direction of Mr Laurence Balls. It is proposed to submit those varieties of cotton produced on the experimental farms, which are suitable for growth in the country, to the spinners for their approval, and to propagate the seed from the approved kinds until sufficient quantities are obtained to be grown upon the State Domains' farms, when they will enter into the general scheme of seed distribution as follows :—

First Generation.—Pure seed produced in the Agricultural Department experimental farms and transferred to Domains.

Second Generation.—Available from Domains for distribution to large cultivators and supervised by Department.

Third Generation.—Available from large cultivators' fields for distribution to medium cultivators.

Fourth Generation.—Available from medium cultivators to be distributed on credit to smallest cultivators.

By this scheme it is hoped to drive out those cottons which have been so contaminated by mixture with Hindi plants and with other varieties, that they have themselves become scarcely recognisable and to substitute annually pure seed from the Department's experiment farms through the channels indicated.

Demonstration Farms.

Having shown briefly the manner in which the quality of cotton is receiving the attention of the Egyptian Government with a view to maintaining its standard, I shall now refer to the method by which the Department has striven to teach the cultivator how he can obtain a larger quantity per acre than he usually does.

Circularising printed instructions among an agricultural population, 94 per cent. among whom are illiterate, is obviously unsatisfactory, unless special facilities are given for reading such instructions to assembled masses in mosques, etc. . . . . We have therefore had recourse to what we call demonstration farms as a primary means of instruction.

Among the demonstration farms conducted by the Department in 1911, eleven were laid out in different parts of Egypt specially as cotton farms, in order to show by comparison with neighbouring fields that, by the exercise of a little more care in cultivation and the employment of less heavy waterings, especially in insufficiently drained land, the crop could be greatly increased. In all the demonstration plots cultivated under the Department's direction, average land or that which had previously given unsatisfactory results was selected and a contract was drawn up by the terms of which the Department had the full direction of all the operations on the land, guaranteed a crop equal at least to that of the neighbouring fields, and permitted the proprietor to obtain the full benefit of any increased yield. The cultivator on his part agreed to pay for, and carry out all the ploughing, sowing, and

irrigation operations according to the directions of the inspectors of the Department. In all cases the results obtained by the Department were better than those of any of the neighbouring fields, and the cultivators in general were so pleased with the results that very large tracts of land were offered to the Department upon which to conduct similar farms in 1912. It was obviously impossible to comply with the many requests received, but in 1912 forty-four demonstration farms were under the direction of the Department upon similar terms, the results from which promised to be quite satisfactory. Owing to the small inspectorate staff at present employed and the manifold duties which have to be carried out by them in connection with the cotton worm campaign and seed distribution, it does not appear to be advantageous to increase the number of cotton demonstration farms further at present. The lessons which have been taught to the cultivators who have visited the Department's farms are chiefly those in connection with the advantages accruing from wide ridging and spacing, thinning of Hindi plants, light hoeing, and light watering. As an example how little faith many had in our methods at the commencement, the proprietors of some of the lands told our inspectors that our wide sowings and infrequent waterings would be disastrous. In spite of this our yields were in some cases double, and in all cases considerably larger than those of previous years.

In conclusion, I may say that it is generally acknowledged that both with regard to improvement of quality by means of our seed distribution, and of the quantity by our demonstration farm methods, we have made an advance, and secured that which is of such great importance for future operations—the confidence of the fellahin."

170. **Fisheries.**—We quote from the Second edition of this work, written in 1897:—

"The fishing revenue obtained by the Government from Lake Menzala, with its 490,000 acres, is £65,000 per annum, or £·13 per acre. From Lake Borollos, with its 180,000 acres, the revenue is £7000, or £·04 per acre. The 60,000 acres of Edku yielded £1500 per annum, or £·03 per acre. Mareotis, with its 70,000 acres, not in communication with the sea, yields an insignificant revenue. The large fishing revenue is due to the fact that most of the lakes are open to the sea, and it is at the openings that great part of the fish are caught. As the revenue obtained by the Government is one-third the value of the catch, the total value of fish caught is £220,000 per annum."

The water entering the lakes has been greatly reduced in quantity since 1897, and the fishing revenue has decreased. We give below a note on Egyptian fisheries as they are to-day, which has been kindly written for us by Mr J. F. G. Hopkins of the Finance Department.

"The principal fishing centres are:—

			Revenue.
Lake Borollos—	Mudiria of	Gharbia	£4,500
„ Menzala—	„	Dakahlia	21,000
„ Mariut—	„	Behera	1,200
„ Edku—	„	„	
„ Karun—	„	Fayum	4,000
„ Bardawil—	Sinai Peninsula		1,200

Fishing is free on the Nile; formerly all boats on the Nile used to require licences, but these were abolished in 1905.

Fishing zones in both Lower and Upper Egypt are leased annually by the Government and are put up to adjudication; there is considerable competition amongst the fishermen to obtain the fishing rights, especially in Upper Egypt.

Large quantities of fish are caught when the water is let out of the basins; fishing is carried on during the whole year in the large canals.

The annual revenue derived from fishing rights amounts to £41,000.

On Lake Karun there is a close season during the months of April and May. This was found to be necessary owing to the diminishing quantity of fish caught, and has had an excellent effect; the size of the mesh of all fishing nets used on the lakes is also being gradually enlarged—a most unpopular measure at first, but the fishermen are now beginning to realise its utility.

In Lake Menzala there is a large spawning area which is strictly preserved throughout the whole year: the work of supervision of the lakes, with the exception of Lake Karun, is most ably carried out by the Coastguard Administration.

The curing of fish is carried out in various centres, the most important being those of Menzala and Borollos. The fish after being cured is known as *Fisikh*, and a favourite article of diet amongst the fellahin, but is rather too strong-flavoured for the upper classes.

The following are the principal varieties of fish caught in the lakes: grey mullet, three varieties—*Mugil cephalus*, *Mugil capite*, and *Mugil auratus* (known locally as *Buri*, *Tobar*, and *Garan*); maigre, *Sciena aquila* (Arabic, *Lut*); *Umbrina cirrhosa* (Arabic, *Shifoh*); soles; ray; *Chromis Niloticus* (known as *Bolti* in Cairo, *Shabar* in Menzala and Damietta, and *Misht* in Suez); catfish of various species; eels, of which a considerable quantity are exported to Germany; *Maloptercerus electricus*; *Lates Niloticus*; Nile perch (*Leffash*, Lake Karun).

References have been taken from the following books: *Zoology of Egypt*, G. A. Boulenger, F.R.S.; *Report on the Edible Fishes of Lake Menzala*, J. C. Mitchell, B.Sc."

The Finance Ministry should not rest satisfied until it has not only restored the fishing industry of the Nile Valley to its old standard, but greatly improved the quality of the fish in the Nile with the aid of the water stored in the Aswan dam. We close this chapter by a quotation from a paper read by General Tchangki-tong at the Paris International Congress of 1889:—

"I may add that without these gigantic irrigation works, the Chinese could never have carried to such a pitch of perfection one of their most important industries. I speak of pisciculture. Thanks to the abundance of water, the whole of my countrymen, instead of contenting themselves with covering with their fishing boats the seas, rivers, and lakes of our country, have devoted themselves to the breeding of fish. The spawn is everywhere carefully collected; far from leaving it to take its chance, the peasant gives this source of wealth a safe shelter in some spot where a perennial supply of water can be assured. The irrigation reservoirs teem with fish. During winter the rice fields are fallow; the water is led into them, and they are instantly full of carp. This industry allows us to make fish a considerable factor in the food of our people. The fish are either eaten fresh; or, salted and dried, they are despatched to all parts of the Empire and sold at a price which is remunerative, though it is exceedingly cheap."

CHAPTER XV.

ADMINISTRATIVE AND LEGAL.

171. Introduction.—172. Land Taxes previous to 1897.—173. Land Tax Readjustment.—174. Earthwork Maintenance Corvée.—175. Nile Protection Corvée.—176. *Decrees* and *Regulations.*—177. Water-lifting Machine Law.—178. Canal Law.—179. Canal Administration.—180. Land, Water, and Manure Taxes.—181. Land Reclamation.

171. **Introduction.**—History tells us that just as irrigation was the oldest applied science in the world, so the first civilised communities on this earth were formed in the irrigated valleys of the Nile and the Euphrates. Once people took to irrigation, they had to form laws and respect them, for disobedience and wilfulness spelt ruin not only to their neighbours but also to themselves. When the water that irrigates your field has to flow in a channel which passes the fields of all your neighbours, and cannot be maintained in a state of efficiency unless all do their duty, it is easy to understand how method, order, and obedience to a properly constituted authority very soon developed themselves. M. J. Brunhes, in his interesting work *L'irrigation dans la péninsule Ibérique et dans l'Afrique du Nord*,* explains with much skill how laws affecting irrigation have gradually been developed in the arid regions of the world according to climatic and geographical conditions. He compares the laws of Spain with those of Algeria and Egypt. He shows how the authority of the Government in an absolutely rainless country like Egypt becomes gradually more and more autocratic, and how the European mixed tribunals of the country, which are nominally independent of the Government, have gradually been forced to admit its absolute supremacy. He also explains how autocracy is introduced in a free community of irrigators on small independent canal systems in Spain. In times of difficulty the irrigators choose from among themselves a dictator for the whole period of scarcity of supply, and his orders are obeyed and respected as though he were an absolute monarch. They invariably choose a good man. M. Brunhes works out his thesis in five hundred pages, and then gives an index of close on fifty pages which contains the names of all works bearing on his subject up to the date of his work.

An earlier work than his was that of Mr Ham Hall,† giving all the

* *L'irrigation dans la péninsule Ibérique et dans l'Afrique du Nord*, by J. Brunhes, G. Naud, 3 Rue Racine, Paris, 1902.

† *Irrigation Development*, by W. Ham Hall, State Office, Sacramento, 1886.

irrigation laws of France, Italy, and Spain up to 1885 in the greatest detail. His is no philosophical work, but one full of information and worthy of study.

In Blue Book, *South Africa*, July 1902, is a rough draft of canal legislation suited to South Africa, drawn up by one of us for Lord Milner.

172. **Land Taxes previous to 1897.**—We extract the following from the Second edition of this work :—

"The standard work on land tenure in Egypt is *La propriété foncière en Egypte*, by Yakoub Artin Pasha, published by the Egyptian Institute in 1883.

The first settlement of the land tax in modern times was made by Mohamed Ali, in 1813, on the completion of the cadastral survey, which measured up all cultivated land. All lands included within the Cadastre, with some notable exceptions, were called *Kharagi*, and made subject to taxation. From among the lands left outside the Cadastre, numerous estates were given gratis and exempt from tax by Mohamed Ali and some of his successors to their families or to their immediate followers. These estates were called *Ushuri*. The majority of them needed works of amelioration. In Said Pasha's time the four provinces of Gharbia, Menufia, Fayum, and Beni Suef were all measured, and the excess found in every hod, or subdivision of a village, was changed from *Kharagi* to *Ushuri*, and handed over to the courtiers and friends of the Viceroy. Later on, in Ismail Pasha's time, the whole of Egypt was apparently thus treated.

At the first settlement of the Kharagi land in 1813 the maximum tax was 50 piastres * per acre in Upper Egypt and 45 piastres per acre in Lower Egypt.

In 1820 there was a second settlement, and in 1839 an increase of 5 per cent. on this settlement was effected.

In 1844 the Kharagi taxes were increased by one-eighth to cover the cost of collection.

Previous to 1854 the Ushuri lands had been exempt from taxation, but in that year Said Pasha subjected them to an impost of one-tenth of their gross yield, on the plea that they should pay their share of the cost of irrigation. This tax could be paid in kind. The maximum tax for Lower Egypt was 26 piastres per acre, and for Upper Egypt 20 piastres per acre.

In 1857 the Kharagi taxes were increased generally by 5 piastres per acre. The maximum tax had now risen to 100 piastres per acre.

In 1864 was made the second great settlement of the land tax, and as far as can be ascertained from employés who were engaged in these operations no inspection of fields or hods was carried out at all, but the information collected from village sheiks and other proprietors summoned to the various governors, etc., for that purpose, formed the chief base on which the tax was fixed. After this settlement the maximum Kharagi taxes were raised to 115 piastres per acre in Lower Egypt and 110 piastres per acre in Upper Egypt, while the maximum Ushuri taxes were 35 piastres per acre in Lower Egypt and 31 piastres in Upper Egypt.

In 1867 the Ushuri land taxes were raised to a maximum of 65 piastres in Lower Egypt and 45 piastres in Upper Egypt.

In 1868 the Kharagi and Ushuri taxes were increased by a sixth as a temporary measure for four years.

* 100 piastres = £1.

In 1870, by an order of the Ministry of Finance, the Kharagi and Ushuri taxes were increased by 10 per cent. to cover the cost of maintenance of the irrigation works. In the same year the Ushuri taxes were classified afresh.

In 1871 the temporary increase of 1868 was made permanent. As the classification of Ushuri taxes in 1870 resulted in a decrease of £60,000 per annum in the land tax, the Ushuri taxes were increased, and the maximum for Lower Egypt became 77 piastres per acre and for Upper Egypt 51 piastres per acre.

In 1880 the Ushuri taxes were augmented by £150,000 per annum, and the maximum in Lower Egypt now became 112 piastres per acre and in Upper Egypt 102 piastres per acre.

In 1884 some of the southernmost provinces of Upper Egypt were permitted to pay their taxes in kind.

Owing to urgent appeals for a reduction of taxation from the southernmost provinces of Egypt, an examination of these provinces was made by Sir Elwin Palmer, Financial Adviser, at the beginning of 1890.

In 1891 the Kharagi taxes of the southernmost Mudirias were reduced by the following amounts:—

Nubia	£14,914
Kena	103,282
Giza (a part of)	9,184
A total of	127,380

In Kena and Nubia the taxes were reduced by 33 per cent. generally, and by 50 per cent. in special cases. In Giza the reduction was 25 per cent.

In 1892 the taxes of those lands which had formerly been put up to auction were fixed at Kharagi rates, and all fractions were removed from both Ushuri and Kharagi taxes. The Kharagi taxes of the following Mudrias were reduced as follows:—

Girga	by £81,651
Remainder of Mudiria Giza	by 34,173
	115,824

In Giza and Girga the reduction amounted to 20 per cent.

In 1894 the Kharagi taxes were reduced in the following Mudirias:—

Assiut (with the exception of lands irrigated by the Ibrahimia Canal)	by £67,667
Minia (ditto)	by 19,832
A part of Beni Suef (ditto)	by 1,847
Total	£89,346

In Assiut the reduction amounted to 17 per cent., in Minia to 14 per cent., and in Beni Suef to 13 per cent.

Between 1891 and 1894 the Kharagi taxes of Upper Egypt were reduced by £332,550, or 17 per cent., and at the end of 1894 the taxes stood in round figures as follows:—

TABLE 269.—LAND TAXES, 1894.

—		Upper Egypt.	Lower Egypt.	Total.
Kharagi	acres	1,717,000	1,975,000	3,692,000
„ taxes	£	1,660,000	2,430,000	4,090,000
„ tax per acre	£	·96	1·23	1·07
Ushuri	acres	472,000	1,073,000	1,545,000
„ taxes	£	165,000	525,000	690,000
„ tax per acre	£	·36	·49	·44
Total	acres	2,189,000	3,048,000	5,237,000
Total tax	£	1,825,000	2,955,000	4,780,000
Tax per acre	£	·83	·97	·91

The registered land, exclusive of that held by the Daira Sania and State Domains Administration, was thus classified in 1894 :—

TABLE 270.—LOWER EGYPT. LAND TAXES, 1894.

	Kharagi.	Ushuri.	Total.
Land paying taxes of—	acres	acres	acres
From 175 to 165 piastres	6,302	...	6,302
„ 164 to 150 „	831,124	...	831,124
„ 149 to 125 „	435,190	...	435,190
„ 124 to 100 „	204,485	37,948	242,433
„ 99 to 75 „	165,986	243,244	409,230
„ 74 to 50 „	83,434	177,059	260,493
„ 49 to 25 „	30,074	176,564	206,638
„ 24 to 0 „	376,875	166,470	543,345
Total	2,133,470	801,285	2,934,755

TABLE 271.—UPPER EGYPT. LAND TAXES, 1894.

	Kharagi.	Ushuri.	Total.
Land paying taxes of—	acres.	acres.	acres.
From 159 to 150 piastres	423	...	423
„ 149 to 125 „	52,454	...	52,454
„ 124 to 100 „	799,877	98	799,975
„ 99 to 75 „	470,504	911	471,415
, 74 to 50 „	179,493	111,826	291,319
, 49 to 20 „	45,395	126,041	171,436
„ 19 to 0 „	35,462	74,718	110,180
Total	1,583,608	313,594	1,897,202
Grand total	3,717,078	1,114,879	4,831,957

It has been already stated that the lands are classed as *Kharagi* or *Ushuri* in the Government registers. The Kharagi and Ushuri lands are again subdivided into *Nihai*, *Moakat*, and *Gher Marbût*. *Nihai* comprises all the lands which pay the final taxes of their category. A single *hod* may contain various categories of Nihai taxed land. *Moakat* comprises the lands which pay temporary taxes of various kinds and whose limit of taxation is the final, or *Nihai* tax of their hod, though some hods have no 'final' land. Land reported as uncultivable passes under the generic name of *Gher Marbût*, literally 'without tax,' in the Government registers. After that land, left outside the Cadastre begun in 1813, had been granted away and made Ushuri, taxes were by degrees imposed upon that part of it which was reclaimed and cultivated. No tax was imposed upon the part unreclaimed, which figured as Gher Marbût up to March 1894, when it was subdivided. That part of it which could be reclaimed by individual effort was taxed according to a light and gradual scale, and so entered the category of *Marbût* or tax-paying land. The balance which could not be brought under cultivation by individual effort, and which needed public works to enable it to be brought under cultivation, still remains in the general category of Gher Marbût.

In addition to this Gher Marbût, consisting, as explained above, of land irreclaimable and uncultivable except by the agency of public works, other land is brought under the Gher Marbût category by the operation of the *Talaf* decree of 1889. This decree does not deal with land that has never been cultivated, but, on the contrary, with land that has been cultivated but has gone out of cultivation, and in every case before exemption is granted the Public Works Department has a voice in determining whether the application for relief should, or should not, be forwarded to the Finance Department. Land cannot remain Talaf without periodical revision.

The base of the existing land tax settlement of Egypt was fixed in 1864. Since then the conditions of irrigation, drainage, transport, population, and tenure have undergone material changes. These changes of conditions have gradually resulted in rendering the incidence of taxation exceedingly light in some places and abnormally heavy in others. One of the first acts of Sir Elwin Palmer, on becoming Financial Adviser to the Khedive, was to recommend heavy reductions of taxation in the southern Mudirias of Upper Egypt, and lighter reductions in others. As already remarked, these reductions amounted to no less than £332,550 in all, and were effected between 1891 and 1894; and since the Government at that time had in its possession no estimated valuation of the country, it reduced the taxes *en bloc*. This system answered fairly well in the purely basin tracts of the south, where, as a rule, the taxes bore some ratio to the rents. When, however, petitions for reduction came from the north and from the perennially irrigated tracts, no such procedure was possible, and at the beginning of 1895 the Government, on the advice of Sir Elwin Palmer, with the full approval of Nubar Pasha, decided to undertake a land rent valuation of the whole of Egypt and to readjust the land tax. This valuation was begun in April 1895, and the Government appointed me Director-General of the operations.

The work was performed by ten commissions. Each commission consisted of two officials and two non-official members. The valuation was completed by April 1897. Its success was in great part due to the valuable advice given by Mr (now Sir Bampfylde) Fuller, K.C.S.I., who was advising the Egyptian Government

at the time on the subject of the Cadastral Survey. Since this valuation was made the Egyptian Government has asked the consent of the European Powers to the reduction of the land tax to one-third the renting value assessed by the commissions on all lands which pay over one-third their renting value. The reduction will amount to £216,000 per annum, and the consent of the Powers has been obtained. Meantime Mr Gorst, the new Financial Adviser, intends utilising the valuations and applying them to the new cadastral maps as they are finished, so that before long the land tax of Egypt will be on a rational and healthy basis.

I extract the following facts from my note-books, as they bear on the agricultural questions before us :—

'One of the *factors governing the renting values of the land* was found to be the wealth or poverty of the resident population. Among the many causes which have helped in recent years to add to the wealth of the fellahin and to raise the rents over the whole of Egypt, the abolition of the corvée and the substitution of paid for unpaid labour have held a high place. While improved irrigation has, as a matter of course, played the principal part, the recent very appreciable lowering of the taxes in the southern provinces and in Giza has given a further impetus to the rise of rents in the provinces affected. If a comparison be instituted between the prosperity and taxable capacity of to-day and what it was ten years ago, it will be found that probably no part of Egypt has improved more than the Nile valley south of Abutig, near Assiut, where the abolition of the corvée, improved irrigation, and a lowering of the taxes have gone hand in hand.

'Where extensive contiguous estates were owned by non-resident landlords, the resident population was found to be poor and the rents comparatively low. Especially was this the case where the lands were let to non-resident middle-men, who sublet to the fellahin at rack rents. Such estates have benefited far less than others from all that has been done in recent years; and not only have their own rents remained low, but they have also depreciated neighbouring properties owing to the excessive poverty of their resident population.

'In the well-irrigated basins of Upper Egypt, especially in Girga and Southern Assiut, and in the Sefi tracts of the whole of Egypt, where drainage was not essential, the *fellahin proprietors* who paid taxes direct to the Government were found to be possibly the most contented and prosperous agricultural community in the world. Their wants were simple, their taxes were low, and now that the canal clearance corvée had been abolished, they were more often buyers than sellers of land. It was not to be inferred from this that taxes were nowhere oppressive, for they certainly were, but on restricted areas and confined to the badly irrigated or badly drained tracts.

'*The proximity of manures in the deserts* or in ancient ruins was found to exert a strong influence on rents. The land-tax adjustment commissions had begun to collect a mass of information on this subject, when Mr Fuller, C.I.E., was invited by the Egyptian Government to take up the question of manures. His exhaustive examination of the question covered the whole ground of inquiry and was embodied in a report which he submitted to the Government. His main arguments might be thus epitomised: "Nile water, though exceedingly rich in potash, which constitutes the principal food of leguminous plants, is singularly poor in nitrogen, on which cereals depend. Indeed, so low is the proportion of nitrogen in Nile water that only choice localities which receive many times their proper

share of red-water deposits can grow cereals year after year, or be double-cropped without the aid of manure. The bed of the Nile rises gradually at the rate of a few centimetres per century, and the rise of the river bed is accompanied by a corresponding rise of the lands irrigated by the red muddy water let into the basins. This rise spread over the whole area represents an amount of deposit which does not contain a fraction of the nitrates needed for cereals. Basin irrigation thoroughly washes the lands, keeps them free from injurious salts, and covers them annually with a deposit of mud which suffices generally for crops of leguminous plants and cereals sown in rotation in alternate years. In some basins the deposits are so rich that two crops can be produced per annum without manure, but this is exceedingly rare; and, generally speaking, a free application of manure is a necessity for a double cropping and for cereals in the poorer basins. In Upper Egypt this manure is almost wholly obtained from the nitrates in the deserts between Halfa and Kena, and from certain ancient ruins such as Abydos, Ashmunen, Medinet Fayum, and others. South of Kena the supply from the deserts is inexhaustible; but to the north of Kena the ancient ruins are being gradually exhausted, and, moreover, supply but a fraction of the area requiring manure. In Lower Egypt, and the more prosperous parts of the Mudirias of Kena, Girga, Assiut, and Giza, where cattle are necessary for lifting water and very numerous, farm-yard manure is very plentifully used."

'The selling price of land was found to vary from sixteen years' purchase in the wealthy villages which enjoyed perfect irrigation and drainage, to twelve years' purchase in ordinary tracts, and even eight years' purchase where irrigation was precarious and drainage deficient. The mean was fourteen years.' "

173. **Land Tax Readjustment.**—We now give in full the succinct report, dated 5th September 1907, of Mr A. T. M'Killop, Chief Inspector of the Ministry of Finance, who directed the final readjustment of the land tax from 1899 to 1907. This readjustment we consider one of the most beneficial acts of the last thirty years.

"The last appeals on the readjustment of the land tax were examined on the 5th of September 1907. The work which was commenced on the 18th of May 1899 is now completed as far as the field operations are concerned. The new rates in the two provinces of Minia and Beni Suef just finished will come into force in 1912.

The inequalities between the rates of tax on what are still generally known as Kharagi and Ushuri lands will then have entirely disappeared.

It is not within the scope of this note to explain the origin of the terms Kharagi and Ushuri,* but it is of interest to recall that all Kharagi lands which were not already freehold in virtue of previous legislation were declared freehold by Khedivial Decree dated 15th April 1891. Thenceforth there was no difference in the form of tenure of Kharagi and Ushuri lands. As regards taxation, however, in neither category did the tax bear any fixed proportion to the yield of the land, and moreover the rates of the Kharagi lands were universally high, whereas those paid on the Ushuri lands were low.

The object of the readjustment operations was to try to equalise the taxes, and make them as far as possible bear a fixed proportion to the rental value of the land,

* Explained in paragraph 171.

at the same time making no reduction or increase in the total amount of taxes collected on the area under adjustment; that is to say, the work was to be a re-adjustment and not a reassessment.

Referring to the taxes previous to the readjustment, Sir William Willcocks says in his report of December 1896: 'In some cases the tax is slightly less than 50 per cent. of the rent, while in others it is actually in excess.'

Successive Financial Advisers had admitted the necessity of readjusting the land tax, but nothing was done until 1895. In April of that year the Government decided to make a general estimation of the rental value of the agricultural land in Egypt as a basis for the readjustment of the land tax. In the order issued from the Ministry of Finance it was laid down that (1) the total tax of the finally rated land should not exceed the amount collected on it at that time, and (2) that the maximum tax of any single acre should not exceed £1·64.

The work was entrusted to ten commissions working under Mr (now Sir William) Willcocks as Director-General. Each commission consisted of a European as P.W.D. member, a native Government official as Finance Department delegate, and two omdas chosen by the people. Their duty was to record the rental value, hod by hod, of all land imposed at final taxes (a hod is a subdivision of a village, and should contain land of the same quality). The commissions worked for twenty-five consecutive days a month, and each was expected to value 1000 acres a day. The work was carried on in Lower and Upper Egypt in summer and winter respectively, the commissions being thus enabled to live under canvas and work without a break from April 1895 to April 1897.

As no reliable cadastral survey maps were in existence at that time, the commissions had to trust to the sheikhs of villages for information as to boundaries of hods and limits of villages. The work was commenced in the best cotton lands in Lower Egypt, commanding the highest rentals, and all subsequent valuations were made by comparison with them. The Director-General, with the assistance of two specially selected omdas, supervised the work of the commissions with a view to bringing about an approximate uniformity of valuation of similar lands in different localities. The Director-General and omdas also heard complaints from landowners objecting to these valuations. A further commission, under the presidency of Mr (afterwards Sir Arthur) Chitty, the Controller of Direct Taxes, was provided to adjudicate in cases of irreconcilable differences of opinion arising between the commissions and the Director-General; but in no case was it found necessary to refer to this supreme authority. They, however, visited various villages throughout Egypt, making exhaustive inquiries as to the work of the commissions, upon which they finally reported favourably.

When the commissions had completed their labours in the fields, the Ministry of Finance calculated the total rental value of each village by multiplying the areas (according to the then existing land registers) by the mean rental values as fixed by the commissions. The total, when worked out, amounted to £16,356,000 on 4,550,181 acres. The land tax collected at this time was 28·64 per cent. of this rental.

The valuations were based on the market value of the crops, and it may be noted that the rentals during 1895–96 were low, as was the price of agricultural produce. The following table shows the value in 1895 compared with 1905 and 1907:—

TABLE 272.—MARKET VALUE OF CROPS.

Crops.	Oct. 1895.	Oct. 1905.	Sept. 1907.	May 1913.†
	P.T.*	P.T.	P.T.	P.T.
Sugar-cane	3	3	3	3 per kantar.
Cotton	180	240	400	380 ,, ,,
Wheat	70	130	110	134 per ardeb.
Beans	70	120	110	134 ,, ,,
Barley	40	70	72	92 ,, ,,
Millet	45	95	70	120 ,, ,,

* P.T. = Piastre tarif, and £1 = 100 P.T. † Added by the authors.

Before substituting the land-tax adjustment figures for the existing taxes, it was necessary to await the completion of the cadastral survey for the following reasons: the existing areas were not sufficiently accurate even for the purpose of taxation, the boundaries of villages were vague and contentious, and the same hod often contained land of different qualities and its limits were frequently ill defined. But temporary relief, to last ten years, was given to all Kharagi lands by reducing to one-third of the rental value all taxes which exceeded that proportion.

The amount of the reduction was £216,000.

In a large number of villages the commissions found the existing taxes almost as high as the rents, the lands deteriorating, and the people exceedingly poor: in others great inequalities, such as Ushuri land rented at £5 an acre and taxed at P.T. 18 in the same village as Kharagi land rented at £2 an acre and paying a tax of P.T. 164. Lord Cromer, referring to the above state of things, says in his Report for the year 1899: 'Without being too sanguine as to the possibility of ever attaining theoretical perfection in the incidence of taxing, it is obvious that such glaring inequalities as the above are wholly incapable of justification.' Immediately after the taxes were reduced to one-third the rental value, so much relief accrued that the state of the land and villages was altered almost beyond recognition. Subsequently, as the survey of the different provinces was completed, the Finance Ministry worked out the total amount required from each village, calculating 28·64 per cent of the rental value arrived at by the commissions.

In May 1899 a Decree was issued, with the approval of the General Assembly, authorising the Ministry of Finance to proceed to the final operations for the readjustment of the land tax: the following is a translation of the principal articles of the said Decree:—

'*Art.* 2.—The mean tax in each village for lands bearing a final rate shall be calculated in the ratio of 28·64 per cent. of the mean rental value as assessed by the readjustment commissions whose labours extended over the years 1895 and 1896.'

'*Art.* 3.—The lands of each village shall be divided into hods containing lands of the same quality; a single rate shall be given to each hod so that the mean tax of the village shall reach that fixed according to Art. 2.'

'*Art.* 5.—The distribution of the taxes in each village, on the basis mentioned in the preceding articles, will be made by Commissions composed of a delegate from the Ministry of Finance, two omdas chosen from the four elected by the

omdas of the same Markaz, the omda of the village interested, and two landowners of the village, elected by the cultivators of the same village.'

'A notice fixing the date of the commencement of operations will be inserted in the *Journal officiel*, and posted in the village, at least fifteen days in advance.'

'Every proprietor will have the right to attend at the time of the assessment of his land.'

'When a commission has completed a village, the result will be published in the village within the following month; from the date of this publication, any proprietor will have the right to appeal. Appeals will be examined and settled by a commission composed of the Wekil * of the Mudiria, as president, an Inspector of the Ministry of Finance, an omda † of the Markaz who will be elected by the commission, and two members of the Provincial Council of the Mudiria, who will be appointed by the same Council.'

'*Art.* 6.—After the completion of work in the Mudiria and the final approval by the Ministry of Finance of the new rates of taxes, they will be published in the village with a notice that the new rates will come into force from the beginning of January, the fifth year following the publication.'

Two Mudirias were completed each year, as follows:—

TABLE 273.—YEARS IN WHICH ADJUSTED TAXES COME INTO FORCE.

Year of Completion.	Provinces.	Year New Rates come into force.
1900	Sharkia and Behera	1905
1901	Gharbia and Giza	1906
1902	Fayum and Menufia	1907
1903	Kaliubia	1908
1904	Dakahlia	1909
1905	Kena and Aswan	1910
1906	Girga and Assiut	1911
1907	Minia and Beni Suef	1912

Two commissions were employed; the first, or Subdivision Commission, consisted of a native official from the Ministry of Finance and the omda and dallal ‡ of the village; its duty was to inspect the lands of every village and determine whether their division into hods by the Survey Department should be final or whether it was necessary to subdivide them. These commissions inspected 58,013 hods and made subdivision in 2,791, being nearly 5 per cent. The second, or Assessment Commission, was formed in each Markaz, of one official from the Ministry of Finance, two omdas elected by the omdas of each district, the omda and two landowners of the village under assessment (the latter being elected by the fellahin). Their duties consisted in examining every field and fixing a final tax for every hod or holding in the village. To enable them to do this, they were supplied with all necessary information and with the cadastral survey map of each village. Following the lines of the previous commissions, they worked consecutively for twenty-five days a month, and completed an average area of 25,000 acres in that time. Their papers were verified in the Ministry of Finance. A notice was then

* Sub-Governor. † Head man of a village. ‡ Village surveyor.

sent to the village recording the tax of each hod, and of each holding where a special tax was given. This notice was posted up in the village for thirty days, during which period the people could appeal to a superior Commission consisting of the sub-governor or the Mudir of the province, an English inspector of the Finance Ministry, two notables from the Provincial Council, and an omda of the Markaz, chosen by the commission.

This Commission, whose decisions were final, held their sittings at the Mudiria, where all appeals were read; in all cases where the complaint was against the rate given to any individual hod or holding, they visited the land under dispute. The power of this Commission, as in the case of the Primary Commission, was limited to the distribution of taxes, as fixed by the Ministry of Finance, within the area of each village. Everything possible was done to give publicity to the work of the commissions both by advertising in the *Official Journal* and by posting notices in the villages. As the new taxes do not come into operation until five years from the date when a Mudiria is finally assessed, the taxes of the last two Mudirias, Minia and Beni Suef, will not be altered until 1912.

The following table shows the number of appeals, received, etc. There are

TABLE 274.—NUMBER OF LAND TAX READJUSTMENT APPEALS.

Mudiria.	Received.	No. of Appeals.	
		Admitted.	Dismissed.
Sharkia	427	141	286
Behera	385	112	277
Gharbia	424	203	221
Giza	52	12	40
Menufia	81	21	60
Fayum	425	90	335
Kaliubia	94	34	60
Dakahlia	382	206	176
Kena	94	16	78
Aswan	38	8	30
Girga	32	16	16
Assiut	53	20	33
Minia	90	33	57
Beni Suef	61	31	30
	2638	943	1695

3385 villages in Egypt and about 1,100,000 land-owners; the 2638 appeals were received from 926 villages: *i.e.*, 27 per cent. of the villages, and 0·024 per cent. of the landowners appealed.

Of course, where extensive irrigation improvements have been made, the just incidence of the tax will be, and is already being, disturbed; but this is unavoidable in a country so dependent upon irrigation, and for this reason the Government is pledged to maintain the new rates for thirty years only, after which period it will be free to proceed to a new distribution. There are, however, many who consider that thirty years should only have applied to rates over P.T. 50.

TABLE 275.—RESULT OF READJUSTMENT OF THE LAND TAX IN EGYPT.

Mudiria.	No. of Appeals.			Result of Assessment in 1899–1907.		No. of Hods.		No. of Villages.	Date of Final Assessment.	Date of Application of New Rates.
	Refused.	Accepted.	Total.	Area.* Acres.	Taxes. £	Divided.	Total.			
Sharkia . . .	286	141	427	427,202	433,682	363	1,876	363	1900	1905
Behera . . .	273	112	385	384,102	394,475	325	2,167	313	,,	,,
Gharbia . . .	221	203	424	665,195	744,996	593	7,893	486	1901	1906
Giza . . .	40	12	52	166,224	159,935	155	1,994	152	,,	,,
Menufia . . .	60	21	81	342,319	543,503	61	5,263	305	1902	1907
Fayum . . .	335	90	425	200,487	136,375	199	3,781	85	,,	,,
Kaliubia . . .	60	34	94	176,219	273,436	26	2,596	149	1903	1908
Dakahlia . .	176	206	382	460,082	465,632	579	7,946	491	1904	1909
Kena . . .	78	16	94	324,080	236,655	53	4,599	133	1905	1910
Aswan . . .	30	8	38	64,730	30,968	31	1,198	74	,,	,,
Girga . . .	16	16	32	304,180	253,447	26	4,489	227	1906	1911
Assiut . . .	33	20	53	394,585	387,864	154	5,866	272	,,	,,
Minia . . .	57	33	90	374,114	372,192	135	5,287	256	1907	1912
Beni-Suef . .	30	31	61	220,893	244,720	91	3,058	169	,,	,,
Total . .	1695	943	2638	4,504,412	4,677,880	2791	58,013	3385		

* Area paying final rates at the time of the new assessment.

Such light taxes as P.T. 14, P.T. 22 and P.T. 29 are too low to be given such a long period, and a shorter one of, say, fifteen years would have been fairer to the Government. At the same time, if these low rates in the north of the Delta will attract some of the surplus population from the congested districts of Menufia and Southern Gharbia, an important step will have been taken towards the ultimate reclamation of the poor land of this part of Egypt. The greatest difficulty landed proprietors have to contend with in these districts is the scarcity of labourers.

Before closing this note, it is a pleasure to record that during the eight years the work has lasted, on one occasion only was a member of a commission considered not to be working honestly, and he was reported by the Moawin in charge of the commission. I could give many examples of the independent spirit in which these commissions did their work. The majority of the members did not inquire into the name of the proprietors of the land. If they were inclined to be partial to any class, it was certainly not to the pashas. In more than one village the Appeal Commission made slight alterations in favour of the large landowner.

Table 275 gives in a concise form the result of the readjustment."

We have the pleasure of recording here the names of the more prominent members who worked so well in the First Land Tax Readjustment Commissions:—

1. *English Secretary :* Mr M. S. O. Walrond,* C.M.G.
2. *Arabic Secretary :* Sheikh Ahmed el Azhari Bey.

Official Delegates.

Messrs H. A. Humphreys.	Hasan Pasha Hasîb.
O. H. Moore.	Ibrahîm Pasha Murâd.
Richardson Bell.	Mahmûd Eff. Âtîa.
R. M. C. Moss.	Àbdel Rahmân Bey Rushdi.
Arthur T. Williams.	Girgis Bey Suriâl.
J. D. M'Killop.	Mohamed Bey Mûsa.
A. T. M'Killop.	Mustafa Bey El Nagdi.
A. S. Withers.	Salîb Bey Sàd.
D. St John Ker.	Mohamed Bey El Sarrâg.
B. C. Paxton.	Mohamed Bey Badì.
John Dixon.	Mohamed Bey Baligh.
Woodley Page.	Mohamed Eff. Saber.

* Afterwards Private Secretary to Lord Milner in South Africa.

DELEGATES CHOSEN BY THE FELLAHIN.

Name.	Markaz.	Mudiria.
Mohamed Bey Metwalli . . .	Santa	Gharbia.
Sheikh Ibrahim	Mehallet Roh	,,
Hasab El Nabi Bey Hasan . . .	Girga	Girga.
Àkl Bey Gheith	Zagazig	Sharkia.
Hamza Bey El Tûkhy	Mansura	Dakahlia.
El Sayed Bey Soleimân	Tala	Menufia.
Mohd. Bey Othmân Abâza . . .	Mina el Kamh	Sharkia.
El Sayed Bey Ayûb	Bilbeis	,,
Mohd. Bey Mashâli	Dahr El Timra	Behera.
Ahmad Bey Abu Hamar . . .	...	,,
,, Bey El Rîdi	Wasta	Beni Suef.
Husein Bey Àbdîn	Giza	Giza.
Àbdoh Bey Mikhaîl	Fashn	Minia.
Àbdel Karîm Bey Àtîa	Badreshein	Giza.
Àly Bey El Àwar	Beni Mazar	Minia.
Mohd. Bey Àbdel Âl el Èkâli . .	Badari	Assiut.
Ismà îl Bey Tammam	Abu Tig	,,
Mahrân Bey Farag	Mallawi	,,
Sîd Ahmad Bey Àtîa el Defeishi . .	Tahta	Girga.
Rashwân Bey Hammâdi . . .	Sohag	,,
Tayè Bey Salâma	Luxor	Kena.
Sayed Bey Wâkid	Sangaha	Sharkia.
Àbdel Magîd Bey Nuseir . . .	Mina El Kamh	,,
Imâm Bey Ismàîl	...	,,
Abu El Futûh Bey Nassâr . . .	Hurin	Gharbia.
Mohd. Bey Tammâm Habarîr . .	Hawamda	Girga.
Harûn Bey Hammâm	...	,,
Àbdel Wahhâb El Òkda . . .	Taranis El Bahr	Dakahlia.
Mustafa Kersha	Sindyun	Gharbia.
Fathalla Bey Barakât	...	,,
Soleimân Bey Ahmad Abaza . . .	...	Sharkia.

174. **The Earthwork Maintenance Corvée.**—We now quote *in extenso*, from the Second edition of this work, written in 1897:—

"The Public Works of Egypt, consisting of canals, roads, and buildings, are administered by a central establishment consisting of a Minister and Under-Secretary of Public Works and a central office costing £33,000 per annum. The Irrigation Department is under two Inspectors-General of Irrigation having under them Inspectors of Irrigation, and Chief and District Engineers. The irrigation budget was subdivided as follows:—

Establishment	£70,000
Contingent charges	25,000
Maintenance of masonry works	55,000
Nile protection works	25,000
Draining Lake Mareotis	10,000
Earthwork maintenance	400,000
Total	£585,000*

In addition to this is the *corvée* or forced labour gangs who guard the Nile banks during flood without payment, and have to provide Indian corn and cotton stalks for protecting the banks against the wash of the waves. The mean annual expenditure on Nile corvée and protection may be put down at £150,000, which brings the total to £735,000.

The sum allowed for original works permits of the annual construction of a certain number of new syphons and regulators. The masonry works themselves, which were previously in a state of disrepair, are being gradually put into working order. The people themselves are naturally untidy and indifferent about the appearance of their works, and it will be many years before ideas of neatness and tidiness will be inculcated. A comparison of the existing masonry regulators, canals, and banks in Egypt with similar works in India is absolutely out of the question. The permanent protective works on the Nile, such as stone spurs and the provision of stakes, absorb the money provided by the State.

When Sir Colin Scott-Moncrieff took charge of the Public Works of Egypt in 1883, the whole of the earthwork maintenance of the country was performed by forced labour or corvée. This earthwork maintenance corvée was finally abolished in December 1889, and was one of the creditable performances of the British occupation of the country.

* The Public Works accounts are unmethodically published and maintenance charges and original works expenditure so mixed together, that exact figures can be obtained for scarcely any item, and there are so many changes in the system that to compare one year with another is almost an impossibility. The best we can work out for 1910 are the following:—

Central Office		£90,000 per annum.
Establishment	£120,000	
Contingencies	50,000	
Maintenance of masonry works	80,000	
Nile protection works	70,000	
Pumping	25,000	
Earthwork maintenance	480,000	
	£825,000—AUTHORS.	

While there was nothing but basin irrigation in Egypt the corvée system, in theory, was not a bad one, as during the working months there was absolutely nothing else for the agricultural population to do except repair the dykes, clear the canals, or protect the banks. The whole community was interested in the canals supplying plenty of water to the basins, and the burden of ensuring this fell properly on all. With the introduction of perennial canals and irrigation in the time of Mohamed Ali, the natural abuses, which must always have accompanied the system, were aggravated by new and special abuses. The whole agricultural population was employed to clear the deep perennial canals, though only a limited number were interested in them. Then, also, began the pernicious habit of moving the corvée from province to province, and keeping them at work through the whole of the summer, while at the same time the presence of water in the deep canals made the absence of the peasantry from their fields doubly trying to them. Said Pasha even employed the corvée on the Suez Canal, while Ismail Pasha used contingents of corvée from all the provinces of Egypt to dig the Ibrahimia perennial canal in Upper Egypt—a canal constructed almost entirely for the benefit of the Khedivial private estates. The programme of work sketched out yearly for the corvée was so extensive that they never completed a fraction of the works before the arrival of the flood made them hurry off to guard the banks. There was no difference made between maintenance and original works. These public abuses, though great, were exceeded by the private abuses, unsanctioned by the State. As the summer irrigation increased, and the value of the cotton crop began to be appreciated, the presence of the men in their own fields began to be more valued; advantage was taken of this by the larger proprietors to keep all their own tenants at home, and make the poorer peasantry, known locally as fellahin, do all the work; while ministers and high officials not only sent none of their own tenants to the corvée, but employed, each of them, some 200 or 300 of the regular corvée to work on their private estates. The fellahin were thus not only compelled to work throughout half the year at canal clearances, but were not allowed to reap any of the fruits of their labours.

The corvée were expected to work about nine months per annum: for the six months from the 15th January to the 15th July they worked at canal clearances and repairs of banks, for the three months from the 1st August to the 1st November they guarded the Nile banks. They had to supply their own tools, such as spades and baskets; they had to provide their own commissariat; and, during the winter and summer, they had to sleep on the ground, moving from encampment to encampment without any shelter except that provided by trees and shrubs. During the flood they built booths for themselves on the Nile banks, and had to provide, at their own cost, lanterns at intervals of 50 metres, and whatever brushwood was necessary for the protection of the banks along the whole length of the Nile, on both banks.

The official basis of the calculation of corvée used to be the census of the male agricultural population, between the ages of fifteen and fifty, which Mohamed Ali took in 1847. The basis now is a certain proportion of the male agricultural population according to the last census. In Mohamed Ali's time, one-fourth of the number were called out every 45 days through the summer, so that the whole corvéable population worked on the canals during the 180 days that the works lasted. This proportion was gradually reduced as the Government officials became

more lax, until in 1881 about one-eighth of the whole number were called out to work every 45 days. The balance represented the large number of men who had freed themselves from corvée. The Khedivial decree of the 25th January 1881 laid down the terms on which certain privileged classes could redeem their tenants from the corvée. Since the decree laid down no penalties for those who neither sent men to the corvée nor paid their redemption money, the natural result was that scarcely anybody paid any redemption money except the State Domains Administration. The Khedivial decree of the 25th January 1881 is the first official document relating to the corvée, and a translation by the late Lieut.-Col. Ross is given here in full:—

Decree of 25th January 1881,

Regulating the Works of the Nile and its Canals.

'Article I. The public works enumerated below are, and will remain, at the charge of the State:—

(*a*) The masonry works, which are of benefit to one or more provinces, existing or to be made, on the Nile and its branches, on its banks, on its principal canals, on the banks of the basins of Upper Egypt, and other banks of general interest.

(*b*) Dredging, comprising all charges of purchase, maintenance, and working of the plant.

(*c*) The furnishing and transport of materials, such as stones, wood, sacks, necessary for the public interest, whether for the conservation of banks and regulators or for the closure of dams and regulators and canal sluices.

II. The quantity and the cost of the works and materials, which shall be at the charge of the State, shall be determined each year in conformity with the rules and regulations established or about to be established concerning them.

The total amount and cost shall be entered in the budget of the Public Works Ministry. But always in whatever concerns the works of the Ibrahimia Canal, the proprietors of the lands affected shall, until the completion of the cadastral survey, remain liable to repay the Treasury the sum which it has advanced for these works.

III. The maintenance or construction of masonry works made or about to be made on the canals or banks, and benefiting either several villages or one or more districts, or one village, or one private property, falls on the proprietors of the lands benefiting by their use or construction.

IV. The following works are constructed and maintained at the cost of the general public:

(*a*) The earthwork, whether of excavation or embanking, and the clearance by hand, whether they affect one or more provinces, or the villages of one or more districts, or a single village or a private property.

(*b*) The watching of the banks and other works during the period of the Nile flood.

(*c*) The handling and working of materials destined for the preservation of banks, and works, and regulation.

The Public Works Councils class these works as follows:—

Works of general benefit; works of restricted benefit (*Mushtarak*); works of private benefit; and divide them between the inhabitants of the provinces and districts.

The works of general and restricted interest are those for which corvée ransom may be paid.

V. The corvée ransom is due from all male inhabitants of the country, of sound health, between the ages of fifteen years and fifty years, with the exception of those indicated as exempt in the next article.

VI. The following are exempt from corvée ransom :—

1. The *Ulema* (persons learned in the Kurân). *Fikis* (those who recite the Kurân). Persons engaged in teaching. Students in the mosques and schools. Persons attached to charitable institutions, *Takias* (shrines), convents, and hospitals.

2. Persons in the service of the mosques, tombs, and holy places possessing regular titles.

3. Priests, monks; rabbis, persons attached to the service of the churches, temples, cemeteries of the various sects, furnished with regular titles, similarly.

4. People having professions or trades who pay professional taxes, and who exercise their calling; also fishermen and boatmen.

5. The watchmen of the villages and hamlets, &c., recognised by the Mûdir of the province.

VII. Every individual liable to forced labour (*prestation*) can free himself by furnishing a substitute.

The following can free themselves by paying a cash ransom :—

(*a*) In the hamlets or settlements (*Ezbas*) which have always existed as isolated, without being a part of any of the neighbouring villages, the inhabitants not reckoned in the census of the villages.

(*b*) Landowning Bedouin and cultivating Bedouin heretofore exempt from the forced labour works.

(*c*) The inhabitants of the villages working on the lands of the State Domains and Daira Sania in Lower Egypt, in the villages where these Administrations have more than 100 acres, on condition that the lands are not let, and under the reserve that the number of men ransomed out of each village shall be limited to those required for cultivation.

For the villages in which rice is the predominating crop, and those which have been, like the rice villages, the objects of a special measure as regards the adjustment of the land tax, the forced labour is obligatory; but, in the annual division of work among the inhabitants of the provinces, there will be imposed on each man of these villages only the half of the quantity imposed on a man of other villages.

VIII. The cash payment of the ransom in the cases in which it is allowed, is fixed in 1881 at 120* (one hundred and twenty) piastres per man in the provinces of Lower Egypt, and at 80 † (eighty) piastres in those of Upper Egypt.

After the year 1882 the amount of ransom per man shall be fixed annually, and notified to the Mudirias by the Minister of Public Works, one month before the commencement of the works. It shall be fixed after consideration of the nature and quantity of work to be done, and the time during which they are required to be executed.

IX. The Minister of Public Works can suspend, for any reasons he judges to be of general benefit to the works, the permission to ransom granted in Art. VII.; he can equally, in case he judges it possible to substitute for forced labour mechanical labour or labour by contract, authorise in a general manner the cash payment of ransom in one or more Provinces.

* £1·20. † £·80.

X. The sums received in each Mudiria as corvée ransom will be entered in a special register, and deposited in the treasury of the Mudiria, and held at the disposal of the Minister of Public Works.

These sums can only be spent on works which have for their aim the reduction or the suppression of forced labour.

XI. It devolves on the Minister of the Interior to summon and keep on the works those subjected to forced labour.'

A Khedivial decree, dated 12th March 1882, issued under the influence of Arabi Pasha, allowed Arab settlers in Egypt to redeem themselves like the inhabitants of the hamlets (*Ezbas*), while the Bedouin were exempted altogether from the corvée. It was also decreed that a commission should be appointed to lay down rules how the redemption money to be paid by the hamlets was to be calculated. A committee was appointed, under the presidency of Ismail Pasha Yusri,* which recommended that every hundred acres of land attached to the hamlets (*Ezbas*) should pay for eight persons. This would have meant £9·6 per hundred acres in 1881. This recommendation would probably have been embodied in a decree had not the troubles of 1882 intervened. This principle of the corvée tax being on the land, and not on the individual, came to the front the moment the party of Arabi Pasha were in power. On the return to power of Ministers who represented the large landholders, the opposite principle of the tax being on the individual, and not on the land, was of course insisted upon. These latter asserted that it was not fair to put the corvée tax on the land because the land tax included a small irrigation tax. Considering that the land tax contained an irrigation tax which was insufficient, it would apparently have been more reasonable to raise it slightly, say 3 or 4 per cent., than to make a poll tax of the balance of it. If the poor had refused to work, and if there had been no means of compelling them, they would have lost next to nothing, while the rich pump owners and landholders would have suffered heavily.

Taking advantage of the decree of 1881, every man of any position freed himself from corvée without taking the trouble to pay the redemption tax, while the *whole* of the corvée fell on the poorer classes. Indeed, no man who owned more than five acres of land went to the corvée. Early in 1885 the fellahin of Kafr Sheikh district appealed for an inquiry into the corvée of their district, and on the Government making the inquiry, it was found that although the cultivated and revenue-paying area of the district was 145,000 acres, the owners of 33,000 acres supplied the whole of the corvée. The State Domains, who owned 53,000 acres, paid redemption money for half their tenants, while the larger proprietors, who owned 59,000 acres, paid nothing. Legally, the fellahin ought to have supplied 438 men for 90 days: they were called on to supply 1091 men for 180 days, and actually supplied 800 men for 180 days.

The first tangible relief to the corvée came in 1885, when the Irrigation Department exerted itself to reduce the work to a minimum both by holding up the water in the Nile to a higher level in summer and by working to levels.

Early in that year Nubar Pasha, the Prime Minister, at the request of Sir Colin Scott-Moncrieff, and with the cordial approval of Lord Cromer, made an advance of £30,000 for making the experiment of clearing by contract certain of the canals of the Menufia and Gharbia Provinces, to see if it were possible to do

* Ismail Pasha Yusri received his education in England.

away with the corvée altogether. The experiment proved that hand labour by contract could on all dry work, and on all perennial canals needing less than 40,000 cubic metres each, replace the corvée. Dredging was recommended for the larger canals. Hand labour by contract had so improved in a few years, that perennial canals needing 100,000 cubic metres of work were so cleaned. In 1886 Lord Salisbury, appealed to by Nubar Pasha, gave his consent to the expenditure of £250,000 towards the relief of the corvée, and, for the first time in the long history of Egypt, the State paid towards the maintenance of the canals. Subsequently, Lord Cromer obtained the consent of the Powers to the employment of this sum from the reserves at the disposal of the Public Debt Commission. They refused, however, to find the remaining £150,000 which were needed to redeem the corvée completely, and the Egyptian Government has, since 1890, found the money every year out of sums at its own disposal. The total relief of the earthwork maintenance corvée costs the State £400,000 per annum. The Nile protection corvée has yet to be redeemed. I now give extracts from Sir Colin Scott-Moncrieff's irrigation reports for 1884, 1885, 1886, 1888, and 1889, to show the steady and determined manner in which the Department accomplished this great and beneficial reform.

Report for 1884—'An army of 125,000 men, working about 150 days, performed about 29,000,000 cubic metres of earthwork. A million of cubic metres can convey little meaning to the ordinary reader, who may be assisted if he remembers that the great pyramid contains 2,400,000 cubic metres.

Mr Willcocks estimates that the partial use of the Barrage reduced the silt clearance of his canals by about 26 per cent., which, if we assume corvée labour as worth 2 piastres per diem, means a saving to the country of about £26,000.

The number of corvée on the works is equivalent to an army of 92,609 working for 130 days in the year—50,162 in Lower and 42,447 men in Upper Egypt; and this, be it noted, does not include the immense numbers forced to guard the banks of the Nile during the three months of flood, unpaid and unfed by the State which requires their services.

I trust that in two or three years the corvée, with all its detestable abuses, will have disappeared from Egypt.

With the measures now in process of being carried out, silt clearances may be reduced by one half or even more. What remains may be done by dredging, or by ordinary paid labour, the burden forming by no means a heavy rate on the land benefited.'

Report for 1885.—'Much discussion took place during 1885 on the question of the corvée, and as I have made this the subject of a separate note, I do not propose to go into very full details here. Mr Willcocks brought to notice the injustice and the abuses connected with it, and he obtained from the Council of Ministers permission to try throughout the whole province of Gharbia, and in two of the five districts of Menufia, an experiment for its redemption. Assuming a tax of 30 piastres per head on all the *corvéable* of a village, he determined by the census the amount leviable from each village, divided this amount by the area of the village lands, and thus laid the rate on the land.

Supposing, for instance, a population 400 *corvéable* in a village consisting of 2000 acres. The ransom money would be $400 \times 30 = 12{,}000$ piastres, equivalent

to a tax of 6 piastres per acre. This was only a voluntary tax, however. The corvée redemption could not be made compulsory, and those who did not consent to it could render their manual service instead. Practically all accepted it, and if it could be made into a law binding on all, high and low, I believe the system would work well and be just. As it was, fighting against all sorts of difficulties, Mr Willcocks managed this first year to maintain his canals without any corvée, and the new contract system only failed in one case, that of the Sahel Canal, to which I have alluded elsewhere.

I should notice, however, that the two central provinces, Menufia and Gharbia, are situated more advantageously for such an experiment than the eastern provinces.

Owing to the impossibility of recovering the whole amount of Mr Willcocks's voluntary rate, the total actually realised was only £22,562, to which he added £16,726, the balance of corvée ransom from former years. His total outlay was £53,962.

In Upper Egypt the impossibility of commanding corvée labour required a special grant of £17,576. In Behera a similar grant of £6000 was required.'

Report for 1886.—'In writing the Report of 1885 I stated what measures were being taken for the relief of the corvée. That year there was an outlay of £116,535, by means of which the unpaid corvée labour was greatly reduced. In 1884 it was equivalent to 165,000 men working for 100 days. In 1885 it was only 125,936 men for the same period. In 1886 the sum spent in corvée relief was £265,066, and the numbers were reduced to 95,093.

But it would not be fair to ascribe the reduction of corvée labour altogether to the money grant. The fact is, that in former years there was always a great deal of useless labour employed, which we have been able to dispense with, chiefly by using the Barrage, partly by grading the canal beds to a proper slope. Before 1885, when no use was made of the Barrage, the irrigation officer could never be certain that the Nile might not fall to R.L. 11·15 metres, as it did in 1878, and efforts were made to deepen out the canals accordingly, so that they might always take in some water. Since then he has been able to count with fair certainty that the surface level will not fall below R.L. 12·80 metres, and there has been no need of clearing the canals deeper. The improvements already made to the Barrage tell chiefly in favour of Menufia and Gharbia. In two or three years' time I trust all Lower Egypt will profit equally. On the other hand, while the corvée did much work no longer needed, it was never able to overtake a great deal of work most essential to agriculture, such as the clearing of branch canals and, still more, of drainage cuts. Yearly it was resolved to clear these channels, and yearly at the end of the season they were left undone. Since the money grant has been given these clearances have been made, and it has been thought better than leaving it altogether undone to do this necessary work even by employing so objectionable an instrument as the corvée. On the other hand, great care has been necessary to guard against the undue use of forced labour in addition to the money grant. There exists in the country a fine old conservative party, who, while they have not the slightest objection to spending in the Provinces whatever money the Government grants, see no sort of reason why so time-honoured an institution as the corvée should not continue.

In three provinces the reduction of the corvée is not satisfactory. In Behera a quite unusual amount of work had to be done. The province is increasing very fast, the *corvéable* population is unusually small. In Kena and Esna there are no English engineers resident. Improvements proceed more slowly there than further north, and I fear the views of the conservative party to which I have alluded carry more weight there than they should. Strenuous efforts must be made to relieve the corvée of these southern provinces.

The alternative to corvée labour is paid labour by contract, regarding which, being a new thing in Egypt, many forebodings were uttered. We were assured that the fellah would not work voluntarily; that the contractor possessed of no local influence would never get men, or succeed in clearing the canals within the time required; that they would be oppressive to the people, etc. All these forebodings have proved fallacious. Here, as elsewhere, men prefer to be paid for their labour, and there has hitherto proved no difficulty in procuring them.

On the 31st December 1885 the Council of Ministers came to a decision regarding the relations of provincial governors to inspectors of irrigation. It was then ruled that there should be two descriptions of contract. For those earthworks requiring the labour of more than 1000 men a day, for masonry works costing above £200, and for all works requiring the use of machinery, the contracts should be made at the Public Works Ministry. For all smaller works the contracts should be made at the governor's office, the contractors being selected jointly by the governors and the inspector of irrigation. Lists are kept of contractors whose offers will be accepted, but the Government is in no way pledged to accept the lowest or indeed any of the offers submitted. On the whole this system has worked well.

The canal clearances for the year are determined by an agricultural council, held in each province about December. The flood or inundation canals, the drainage cuts, and the repairs of the embankments, can be done leisurely throughout these months, and there has been no difficulty in finding contractors to do them.

There remain the deep perennial canals, on which depend the cotton and sugar-cane cultivation. These cannot be kept closed in spring or summer for more than three weeks or a month, and their bottoms, nearly 20 feet deep, below steep rugged banks, are always full of mud and slush. Their clearance has been our one contract difficulty, and hitherto we have not succeeded in solving it as we had hoped to do by dredging.

The dredging contracts have been altogether badly drawn up—a circumstance I regret all the more that I am directly responsible for them.

The failure of the contractors on some of the deep perennial canals forced us to employ corvée. It was decided to pay these men for their work, and the sum of £8076 was thus spent altogether, the rate fixed being 2 piastres per cubic metre. This payment of corvée was altogether a new thing. Mr Garstin describes as follows the way it was worked:—

" Lists of men working were kept, village by village, and the amount done by each village as far as it could be estimated. When the work was done, an official on the part of the canals, accompanied by the wakil of the mudiria, went round to each village and distributed the money. Of course the fellahin did not receive all the money put down for them, as a certain proportion must have found its way into the hands of the sheikhs, etc. Still, I believe that they got the greater portion of it, for this reason, that they took the keenest interest in it themselves, and constantly

asked me about it, whereas since the distribution I have not heard a single complaint on the subject."

I have not lost hope that we shall one day dredge all these canals. In the meantime, Mr Garstin made a successful experiment last November. At that season there is no demand for irrigation, and everything is to be gained by closing the canals and allowing them to act as drains, to run off the surplus water from the fields saturated by the Nile flood. This season has never been used for canal clearances, chiefly because the agricultural councils have not then decided on their operations. But this last year, counting on the water level being lowered on all sides, by the closure of neighbouring canals, Mr Garstin gave out the clearance of five of his most difficult ones to contract. The deposit was about 1·25 metres deep in them. At the price of 4 to 5 piastres per cubic metre he succeeded in having them well cleared, the contractors pumping the beds dry before beginning work.

The contract system, with its active competition, has very much reduced rates. The rates per cubic metre for earthwork have been somewhat as follows in Lower Egypt:—

	Piastres per cubic metre.
Excavation of new canals	2 to 3
Clearance of canals, dry	1·5 to 2·5
Clearance of deep perennial canals, wet	4 to 6

In Upper Egypt the rates are somewhat lower. Captain Brown expresses special satisfaction at the good work done in the canal clearances and repairs to banks in the Province of Girga. The amount of earthwork was 1,378,551 cubic metres, costing £18,009, or a mean rate of 1·3 piastres."

Report for 1888.—" A further extension this year was made in corvée abolition, by the permission, accorded after much discussion, to the whole corvéable population of certain provinces to redeem themselves. It was an experiment, and was confined to the Provinces of Sharkia, Menufia, Gharbia, Giza, Beni Suef, Minia, and Assiut. The districts of Gafaria, Zifta, and Mehallet Roh in Gharbia were exempted, and furnished corvée as usual. The ransom sum was fixed at 40 piastres per head generally throughout Lower Egypt, and for lands on the Ibrahimia Canal; 20 piastres in rice districts; 30 piastres in Upper Egypt generally. It was not until February that the measure was sanctioned, when corvée work was already begun and in progress. The difficulty at once arose as to who were the corvéable. The old census of Mohamed Ali was entirely out of date. The census of 1882 was not relied on. Some mudirs, like that of Beni Suef, gave up in despair, and not a man in the province ransomed himself. In Minia things were hardly better. But the active and intelligent Mudir of Assiut found 59,000 men willing to pay ransom.

Among the peasant proprietors of Lower Egypt the corvée redemption has been very popular, and large numbers have readily paid. It is not so among the proprietors and owners of *Ezbas* (hamlets). Many of these are Europeans, and they look on themselves generally as a privileged class, who are entitled to all the State can give them, without rendering the slightest service in return. Mr Willcocks calculates that while the numbers who paid ransom money per 100 acres were among the fellahin of Menufia at the rate of seventeen men and in Gharbia of seven men, the holders of *Ezbas* paid in Menufia only for two men per 100 acres

and in Gharbia for two men for 500 acres. The glaring evil, we must hope, will be rectified ere very long.

The dredging done in the three eastern provinces was, on the whole, satisfactory. It amounted to 637,599 cubic metres against 802,795 done in 1887; but as 206,812 cubic metres dredged in 1887 were not paid for until 1888, they appear in financial accounts as belonging to the latter year. Of course it would be more satisfactory if such a large quantity were not required, but clearance done by dredging instead of hand labour is generally a gain.

In Behera, Mr Foster reports that, for the first time, the dredging was done in a satisfactory manner. The volume dredged in the Rayah Behera and Khatatba canals was 563,745 cubic metres, against 522,111 in 1887."

Report for 1889.—"The year 1889 will ever be memorable owing to the abolition of the corvée, or forced labour, in December 1889; so that in 1890 there will be no forced labour throughout Egypt for the clearances of canals and repairs of banks. The corvée was abolished in December 1889, and for £400,000 the Public Works Department undertook to do all earthwork repairs."

175. **Nile Protection Corvée.**—We quote from the Second edition:—

"*The quantity of work* to be performed annually is determined as follows. Immediately after the flood the district engineers sound all the canals, and estimate the quantity of earthwork necessary in the perennial and flood canals separately, and in the banks and drains. These estimates are generally completed by the 15th December. They are submitted to Councils of Agriculture,* composed of the governors, the irrigation officers, and the village notables in each province. The councils meet in the first week of January, discuss the estimates, and pass them. The total expenditure of each canal is not allowed to exceed the sum allotted by Government.

Up to the present, only the *corvée* on the earthwork maintenance has been considered; we now come to the *protection of the Nile banks in flood.* The Khedivial decree of the 6th August 1885 contains the regulations on this subject:—

KHEDIVIAL DECREE, OF THE 6TH AUGUST 1885.†

'All those inhabitants who are bound to supply corvée by the decree of the 25th January 1881, are equally bound to protect the banks of the Nile in flood.

On the 1st July the Minister of Public Works will point out the points which ought to be protected and watched, and the number of men to be supplied.

On the 15th July an assembly will meet in each province, presided over by the mudir of the province, and having as members the village notables and assistant engineers and executive engineer of the province. The President will communicate to the assembly the instructions received from the Ministry of Public Works relating to the number of watchmen to be provided, and the assembly will divide them among the districts and villages.

Each village headman must forward to the mudir of the province, before the

* These Councils of Agriculture were instituted in 1871. The two Khedivial decrees which refer to them are dated 31st December 1871 and 6th February 1874 respectively.

† All the original decrees and regulations in paragraphs 175–177 are in French. The translations in this book were made by the late Lieut.-Colonel Ross.

25th July, a nominal roll of all the men his village has to supply, divided into two lists.

The men in the first list will be at their posts on the 1st August, and those of the second list by the 1st September. The posts are not to be left by the watchmen, except on a special order of the Minister of Public Works.

The assembly of each province will select four notables, who, presided over by the executive engineer of the district, will form a commission for judging delays and contraventions on the part of the village headmen or the corvée.

Any head of a village or district, or any notable who neglects to supply the number of men required for his section, or who is absent from his post, or who quits it without permission, is within the twenty-four hours to be judged by the commission, and condemned to an imprisonment of not less than twenty days nor over three months, and to a fine of not less than £2 nor over £20. The man found guilty may be definitely dismissed from his post, if the commission considers it necessary, without prejudicing any damages which may be claimed from him, if damages have occurred owing to his absence or carelessness. If dismissed, he is to be immediately replaced by another notable.

If a corvée man fails to be present at his post, he shall be immediately judged by the commission, and condemned to an imprisonment of between twenty days and three months, and to a fine of from £1 to £10. In this case the village headman must immediately produce another man.'

By a ministerial order of August 1887 the date for the first section of the corvée to turn out was changed from 1st August to 15th August. This was owing to representations made by the Ministry of Public Works that there was never any danger between the 1st and 15th of August; while this fortnight was especially valuable to the fellahin as the time of putting in the Indian corn crop.

The Khedivial decree of the 25th January 1886 laid down the punishments to be inflicted on the corvée who were absent from their work during *the canal clearances.*

The commissions appointed by the decree of the 6th August 1885, *for Nile bank protection*, were called on to judge these cases which were made applicable to the Nile corvée.

"Any village headman or notable who neglects to furnish the number of men due for his section, or who is not present at his post to supervise his work, or who leaves his post without permission, is to be judged by the commission within the twenty-four hours, and condemned to an imprisonment of from ten to thirty days, or to a fine of from £2 to £5. He may not be dismissed from his post of village headman.

Any corvée man who fails to be present, or who deserts his post, is to be immediately judged by the commission, and condemned to a fine of £·5 to £1, and to the performance of the work due from him. If he cannot pay the sum due from him, he must perform an amount of work represented by the fine.'

These two last decrees are the outcome of the abolition of the kurbâsh. In the old kurbâsh days the corvée used to be flogged, now they are tried and punished in other ways.

Reading the above decrees, one might assume that these popular assemblies and popular tribunals would work well. When it is considered, however, that the men

to be condemned to punishment are the village headmen and the fellahin, while the real culprits are the large absentee proprietors and their tenants, it will readily be understood that the wrong men are generally punished. The assemblies would never dare to punish the tenants of a large proprietor or to report the delinquency of the proprietor himself. Many village headmen would send themselves to prison sooner.

Before leaving the subject of administration I should be doing a wrong to the Egyptian engineers with whom I have worked for so many years if I were not to put on record their very substantial grievances. Government servants are expected to live on their salaries. It is always assumed that their emoluments will suffice for all reasonable expenses. Now, what are the facts of the case? Young men of from sixteen to twenty enter the polytechnic school, and, after a four years' course, if successful, are appointed to the Public Works Department at salaries of from £4 to £6 per mensem.* Their promotion is exceedingly slow, and I know really capable men who, after ten years' service, are only drawing £8 per mensem. Government has all these years asked these men to live up to their position, in the districts to which they have been appointed, on salaries which are not a half of what they have had to spend, and which the Government well knows that they have all along spent. These unfortunate men have been compelled, whether they have liked it or not, in almost every individual case, to take bribes and rewards, and become a byword and reproach in the country. Some, with naturally predatory instincts, have been let loose to prey on the country, and make their fortunes as quickly as they can, before they are discovered and replaced by others as bad as themselves. Others, with shame and humiliation, have been gradually forced into a life of petty theft and misappropriation at first, and afterwards of open fraud and dishonesty. The salaries of these same men when they climb to the higher appointments are sufficient to enable them to live upright lives, but the habits of dishonesty which they learn at the beginning of their career cling to them to the end. There are, of course, a few absolutely upright men whom no bribes can tempt, and occasionally, of course, men are found who have married into wealthy families or who have wealth of their own, but these constitute a very small minority. There is not a man in the country from H.H. the Khedive and Lord Cromer to the smallest official in the Finance Department, who does not know that every word I say is true of very many of the departments, and especially of the Public Works Department.

Turning to a pamphlet written by Sir Elwin Palmer, financial adviser, published by the Egyptian Government, and entitled *Statistical Returns*, 1881 to 1897, we come upon the following sentence :—

'The expenditure on public instruction has been increased by over 37 per cent., the number of schools has risen from 29 to 51, and the number of pupils from 5366 to 11,304.'

When it is considered that 650 teachers are paid for teaching honesty and justice to 11,304 scholars, and that the great majority of these scholars who enter Government service will be compelled, one after the other, to unlearn all that they have learnt, and make a living from theft and dishonesty, the true reformer sees little to rejoice over. It would be better to close half the schools, and devote the savings to the provision of decent salaries for the scholars who have succeeded in

* Now much improved.

entering Government service. No well-paid European, who is enabled to live an honest and upright life, has any right to cast a stone at his unfortunate Egyptian colleague who does not enjoy equal advantages. The history of the East Indian Civil Service is full of instruction on this point. The old Bengal civilians of the eighteenth century who received nominal salaries, and who shook the pagoda tree to some purpose, were all Englishmen who were corrupted by the fact that their honest emoluments were notoriously insufficient. It was not till Lord Cornwallis introduced his wise reforms, and trebled and quadrupled the salaries, that the public services became what they are to-day."

Since the above was written, the salaries of the young engineers, joining the service, has been increased to £12 per month. It might be brought nearer to £20 per month, which is what young Englishmen get. The Egyptian can live more cheaply in his own country than the Englishman, but he marries early as a rule and is the better man for marrying early.

176. **Decrees and Regulations.**—The decrees and regulations which concern the Irrigation Department up to July 1892 are to be found in Chapter III. of *La legislation en matière immobilière en Égypte*, compiled by the late Sir Eldon Gorst. Mr W. E. Brunyate, C.M.G., Khedivial Counsellor, has published all the decrees of the Government up to November 1911 in *Index of Legislation in force on 1st November* 1911. Decrees and regulations issued since that date are to be found in the *Journal officiel*, of which a very good index is published annually.

177. **Water-lifting Machines Law.**—The pumping engines on the Nile and the canals are subject to a special law :—

Decree and Regulation for Water-raising Machines, 8th March 1881.

"Article I. It is, and remains forbidden to establish engines to lift water for irrigation or drainage, whether fixed or movable, whether their motive power be steam, water-power, or wind, without having previously obtained an authorisation of the Ministry or of the Public Works services. This authorisation does not give to the person benefiting by the use of the engine any right of property, *in any limit whatever*, in the public or private State Lands occupied or traversed by the pipes, conduits or aqueducts of the sluice and place of intake.

The Government does not concern itself in any relations between the person benefiting from the use of the engine, and other parties ; it lays on the licensee the responsibility for all hurtful acts or other injuries caused by erection of the engine or otherwise.

II. The establishment of stationary water-lifting engines will not be allowed except on the banks of the Nile: but the Ministry of Public Works may in exceptional cases authorise their erection on certain canals.

The Ministry alone is the judge of the suitability of the erection, and reserves to itself the free liberty to impose (in considering the special case) any obligations and conditions it considers necessary.

III. Every water-lifting engine, whether stationary or movable, is under the common obligation to leave completely free the circulation on the banks and canals; to respect all the *servitudes* in force ; to hinder in no way the necessary works

for the maintenance of these banks and canals, and for the defence of the country against inundation.

IV. Failure to comply with every or any condition or obligation imposed by the licence to establish a water-lifting engine, will give Government the full right to cancel the licence, without in any way waiving rights which the Government possesses and reserves to itself of carrying out the necessary repairs and reimbursing to itself the cost of the repairs.

V. An engine licensed for a given place cannot be displaced without the issue of a new licence ; no new licence fees will be payable.

VI. The Government reserves to itself the right by reason of public utility (construction of public works, danger to the banks, masonry works, etc.), to displace any licensed engine.

VII. The licence to erect an engine (whether stationary or movable) to raise water, does not grant the right for the licensee to set up a machine to take water from the Nile or a canal. It does not lay the Government under any obligation to maintain a continuous supply of water to the engine. For the passage of water raised by the engine the licensee must arrange with his partners or other parties whose lands it is necessary to cross, without any intervention of any sort on the part of Government. For the passage of water across the waste lands or other lands of Government, the licensee must obtain a special permission.

It is forbidden to make watercourses for the passage of the water raised by the engines, either along the banks of the Nile or the canals, or along the berms or bank-slopes of the Nile or canals.

VIII. The watercourses or conduits to take the water to the fields will be established in such a manner as will not impede either the traffic on the banks, whether of men or beasts, or the circulation of drainage or irrigation water. The licensee alone shall remain responsible for all the rights of other parties for the passage of traffic or drainage or irrigation water. The Government will decide on all the works that the licensee must construct, necessary for the passage of his water under the road and banks, and above and below the canals crossed by the watercourse.

IX. By reason of public utility, in case of an exceptionally low summer supply, or when the discharge of a canal becomes notoriously insufficient for the demands of the cultivation on it, the Public Works services can, by a measure applicable to a whole canal, or one reach only of a canal, order a temporary stoppage of engines for raising water, or may order a reduction in their speed and discharge, in taking into account, if necessary, the relative importance of the machines and of the lands they irrigate. In these and similar cases the Government does not incur any responsibility for damages caused to crops.

X. In suspension of Art. VII., the Ministry of Public Works can, as an exception, authorise the use of a public Nili canal (a Nili canal is one which flows only during the Nile flood) to conduct the water raised by the engine to the lands it is destined to irrigate, and this authorisation is granted under the following reserves :—

(1) The permission is only granted for one summer season, which ends when the Nile water enters the canal by natural flow.

(2) The permission is only granted if the proprietors of the lands irrigated naturally by the canal have given their unanimous consent to this permission.

(3) If it has been found necessary to make dams in the Nili canal to hold up the water, the dams must be of earth, and must be cleared away by the proprietor of the engine before the Nile water flows naturally into the canal. In the case of his not doing so the Government will remove the dams at the cost, risk, and peril of the engine proprietor before the Nile water rises naturally into the canal.

(4) Finally, the proprietor of the machine is alone responsible to other parties for all damages done by breaches in the banks, percolation, and delay in the raising of the banks during the time of supply of water from the engine.

XI. Every person who, contrary to the rules in force previous to the present decree, shall have erected a stationary or movable engine without licence, must, before the 31st August 1881, apply for a licence under the conditions imposed by the present decree and its regulations. All persons possessing a licence issued before the coming into force of the present decree must, before the same date, provide himself with a new licence under the same condition, and he shall not be liable to pay new licence fees.

XII. After the 31st August 1881, every engine established in opposition to the conditions of Art. II. above noted, shall be stopped from working.

XIII. The proprietors of engines are responsible for the damages or accidents occasioned by their engines; the Government, however, reserves to itself the right in the public interest, of inspection of these engines without relieving the proprietors of the responsibility under which they lie.

XIV. Regulations for putting in force this decree, and to the observance of which those interested are bound, shall be framed by the Ministry of Public Works.

XV. Our Minister of Public Works is charged with the execution of the present decree."

Ministerial Order.

Regulations applicable to Water-raising Engines.

"Article I. Every application for the licensing of a movable engine for raising water shall be made on stamped paper, and addressed to the Mudiria or the local Governor's office, in the circle in which it is desired to erect the engine.

The application must contain the following information:—

(1) The class of engine and its pump, with details of the horse-power and principal dimensions.

(2) The site of erection, with a plan.

(3) The work which the engine is required to do: irrigation or drainage.

(4) The names in full, professions, nationalities, residences of the proprietors of the land it is proposed to irrigate or drain.

(5) The period for which the licence is required.

II. The application for licence, registered in a special register in the Mudiria or local Governor's office, will be numbered in sequence after payment of a fixed fee of 100 piastres * to cover cost of examination. It is then transmitted for examination to the engineer-in-chief of the circle in which the Mudiria or local Governor's office exists.

III. The engineer-in-chief of the circle accepts the licence if he thinks fit, and signs the licence, which should contain:—

* £1·00.

(1) The agreement of the engine proprietor to conform to the present regulations and to all future legislative enactments or future regulations.

(2) The exact description of the site of the engine, with a sketch illustrating it, if he thinks fit.

(3) The special conditions of the engine, notably those relative to the culvert under the bank of the canal at the head sluice; its mode of closure, etc.

The licence not being necessary for the public benefit, it is to be well understood that private persons are free to demand compensation from the proprietor of the engine for any rights, etc., they enjoy in the lands where the engine is to be erected, or to oppose its erection in a legal way.

IV. The licence sent by the engineer of the circle to the Mudiria or the local Governor's office is to be signed by the engineer of the circle (Inspector of Irrigation) and sent by the Mudir or Governor to the engine proprietor in order to obtain his signature to a duplicate copy of the licence, which is transcribed on the register itself of applications; and on payment of a fee of 50 piastres * per horse-power. This tax, however, shall never be lower than 500 piastres, or £5·0.

V. All applications for a licence for the erection of a stationary engine must be addressed on a stamped paper to the Ministry of Public Works, which grants directly the licences, if it thinks fit. The application shall always be accompanied by a plan of the whole site of the proposed erection of the engine and its sluice, and in default of a plan of the machinery, a detailed description of the machinery shall be sent in.

VI. The licences for the erection of a stationary engine are taxed on the same scale of fees for examination and licence as for movable engines.

These fees are payable at the Treasury of the Public Works Ministry.

VII. On no pretext whatever can the applicant for a licence put in hand the works necessary for the erection of plant or engine before he receives the licence.

VIII. No engine for raising water may be established on the head sluice, regulators, weirs, or other masonry works of public interest, or near these works, without the distance being fixed in each case by the Ministry of Public Works.

IX. The licence indicated in Art. 5 of the Decree of the 8th March 1881 shall be given by the engineer-in-chief of the circle, who will notify to the Mudiria or local Governor's office the site which he has authorised.

X. The displacement of engines indicated by Art. 6 of the Decree of the 8th March 1881 cannot be ordered, except by the Ministry of Public Works. The displacement shall be carried out at the cost of the proprietor.

XI. All regulations and rules heretofore in force are cancelled, as far as concerns the present regulations."

The following is a translation of the decree of the 12th April 1890:—

Decree of 12th April 1890.

The Construction of Watercourse Heads or the Erection of Water-lifting Machines on the Canals.

"If a proprietor wishes to construct a watercourse head or erect a sakia or water-lifting machine on a canal bank in order to irrigate his land, he must present

* £·50.

his demand to the Governor of the province, who will send it to the Inspector of Irrigation with his opinion and remarks, if he has any. The latter will forward it to the chief engineer of the province, who, if he approves of the proprietor's demand, will give the necessary permit in the case of a sakia, or submit the question for the approbation of the Inspector of Irrigation if it refers to a watercourse head. A copy of the permit must in any case be transmitted to the Governor of the province, accompanied by a declaration that the discharge of the canal allows of the construction of the watercourse or the erection of the sakia without inconvenience to the proprietors of other watercourses situated downstream of it.

The chief engineer shall first exact from the petitioner an engagement to make at his own expense all the works necessary for regulating the discharge of the water in the watercourse, or for maintaining the banks of the canal in proper condition.

The chief engineer has to fix the site of the watercourse head or the sakia. The procedure for erecting stationary or portable engines, worked by steam, wind, or water, is regulated by the Act of the 8th March 1881.

In no case can sakias or water-wheels be erected without permits previously obtained from the Government. This permit, if it is granted, shall be given free."

178. **The Canal Law.**—We quote from the Second edition of this work:—

"Previous to the passing of the canal law, irrigation matters were referred to a few articles of the codes applicable to the native and mixed tribunals. The following are from the native tribunal codes: those in the mixed tribunal codes are practically the same (*L'irrigation en Égypte*, par J. Barois):—

1. The court of summary justice decides finally all cases of less than 10*l.*, while all cases exceeding this sum, however great the urgency may be, are subject to appeal, . . . for damage to fields, fruit and produce, whether caused by men or animals.—[*Art.* 26, *Code de Procédure.*]

2. The right to use the water of the canals constructed by the State is proportional to the lands to be irrigated, except in so far as is provided for in the special laws, decrees, and rules.—[*Art.* 31, *Code Civil.*]

3. Anyone who has constructed a canal has the sole right to use this canal, or to sell it.—[*Art.* 32, *Code Civil.*]

4. Everyone is held liable to provide on his estate a passage for the water necessary for the lands furthest removed from the head of the watercourse. The courts will first decide the amount of indemnity due; and in case of dispute the works necessary to be carried out, so that the water may be conducted through the estate with the least possible damage.

5. The proprietor who irrigates his lands by means of machinery or of canals cannot compel the lower lands to receive the water from his estate.—[*Art.* 33, *Code Civil.*]

6. The public domains are unchangeable, and cannot be seized or alienated. The Government alone can dispose of them by law and decree. They comprise . . . the rivers navigable by boats or rafts, and the canals of which the maintenance is at the charge of the State.—[*Art.* 9, *Code Civil.*]

7. Form equally a part of the public domains the *servitudes* of watercourses, of public works, and more generally all the active *servitudes* of common right attached to the property of the public domains, or which can result from the laws or decrees passed in the public interest.—[*Art.* 10, *Code Civil.*]

8. He who, by breaching the banks, or in any other manner, shall have caused mechanically an inundation, will be, according to the gravity of the offence, condemned to hard labour for a certain time or for life.—[*Art.* 334, *Code Penal.*]

9. Whoever will have voluntarily destroyed, or overthrown, or damaged, by any means whatever, entirely or in part, bridges, aqueducts, banks, . . . belonging to another, . . . will be condemned to an imprisonment of from three months to two years, and to a fine equal to a quarter of the cost of restitution.—[*Art.* 336, *Code Penal.*]

10. Will be punished by a fine of from £·05 to £·25, those who will not have conformed to an administrative order, when this order shall not have determined beforehand the punishments to be inflicted for infractions.—[*Art* 341, *Code Penal.*]

11. Will be punished by a fine of from £·5 to £1·0, and by six days' imprisonment, those who will have injured . . . the public roads . . . or other places of utility, or those who will have encroached on them.—[*Art.* 347, *Code Penal.*]

Previous to the 12th of April 1890, there was no canal law. On that date was passed the first canal law, which was modified by the decree of the 22nd February 1894. The law of the 22nd February 1894 has the following forty-three articles, of which the headings are here given.

To show how necessary a law of some kind had become, I shall give two instances out of many which came under my own notice. At two regulators on irrigation canals, Greek tradesmen had built shops on the upstream wings, and practically taken possession of two important works. As they had roofs over their heads, they were protected by the capitulations, and the Government had to submit to the indignity of not being able to utilise its own works without their permission. As the law was powerless, I was only able to force them to quit by building walls round them, on land which was of course Government property, and starving them into surrender. In another instance, a small colony of Greek settlers had filled up a village watercourse about 2 kilometres long and 4 metres wide, had sown it with cotton, and were on the eve of forcing the helpless villagers to sell their land, now become valueless, for a nominal sum. Fortunately, the British occupation had caused a new day to dawn upon the country, and the villagers appealed to me. I had the cotton cut down, and the canal re-dug, while a number of Greeks, with old revolvers and firearms, threatened to shoot the contractor if he continued his work, and indeed if an Englishman had not been present they would not have hesitated to carry out their threats. These facts will give an idea of the straits into which the capitulations had driven Egypt, and from which nothing but a strong executive could have rescued it.

The Egyptian Canal Act of February 1894.

Art. 1. Canals and public embankments.
" 2. Private watercourses.
" 3. Drains.
" 4. Works for protection against inundation.
" 5. Powers of inspectors of irrigation and of chief engineers.
" 6. Servitudes on land.
" 7. Stoppage of pumps, or closure of canals.
" 8. Construction of perennial watercourses.

Art. 9. Passage of water across another's land, in absence of other means of irrigation.
,, 10. Insufficient volume of a watercourse.
,, 11. Change of watercourses.
,, 12. Construction of sluices, or erection of water-lifting machinery on the canals.
,, 13. The suppression of a watercourse to prevent damage.
,, 14. Diminution in the size of the culvert of a water sluice, or alteration of its floor level.
,, 15. Construction of a drain passing through another's lands.
,, 16. Repairs of a watercourse to prevent damage.
,, 17. Shifting the position of a watercourse which does not meet the requirement of irrigation.
,, 18. Of the difficulties that may arise regarding the repairs of a watercourse.
,, 19. Destruction of embankments, or filling in of watercourses or drains.
,, 20. Removal of trees planted on the banks and slopes of canals.
,, 21. Permission to cultivate on the banks or in the bed of a canal.
,, 22. Transformation of a cultivated embankment into a public road.
,, 23. Construction or repair of a culvert in the bank of the Nile or of a canal.
,, 24. Works of defence against inundation.
,, 25. Diversion of the course of the Nile.
,, 26. Loading and unloading of boats.
,, 27. The valuation commission.
,, 28. Boat owners have no claim against Government.
,, 29. Wreck or sinking of boats.
,, 30. Establishments of ferries on canals.
,, 31. Right of boats to lade or unlade on the banks of the Nile or canals.
,, 32 to 37. Contraventions.
,, 38. The composition of the procedure commission for the trial of offenders, and the special committee for hearing appeals.
,, 39. The Ministry of the Interior to make special rules for procedure to be followed.
,, 40. Responsibility of village headmen and urban authorities.
,, 41. Method of recovering fines.
,, 42. All previous laws are cancelled.
,, 43. The Ministers of Public Works, Interior, Finance and Justice are charged with the execution of the decree."

Articles 6, 8, and 15, and others of a similar nature were not applicable to foreigners for many years, but quite recently the Powers have given their approval to European landowners being on the same footing as Egyptians. With this valuable reform secured, the Irrigation Department should hasten a new Canal Act for the country. The Canal Acts of 1890 and 1894 were drawn up while we were still ignorant of many matters connected with Egyptian irrigation, and a new Act, thoroughly up to date, would meet a real want.

179. **Canal Administration.**—There is a well-known saying in Egypt to-day that it is neither H.H. the Khedive nor the British Consul General who is the real master of Egypt, but it is the canal watchman, who bears the two massive keys which open and shut the portals of our earthly paradise. And it is Solomon himself who tells us that the earth is disquieted when servants bear rule. Owing to the enormous increase of official correspondence in recent years, the Inspectors of Irrigation are so tied down to their offices that it would be physically impossible for them to spend nearly the whole of their time in the provinces as we used to do in the early days of the Occupation. Many an Inspector would give much to be able to say, as the Director General of Irrigation Works in Bagdad was able to say at the close of 1911, that at the end of the official year, the last letter written to his immediate chief was No. 3. A rush round on a motor-car enables an officer to inspect his works and see that one side of his task is being well performed, but the more important side of keeping in intimate touch with the landowners and fellahin is neglected. In the old days, when we had no roads and very few inspection houses, we had in the winter to put up with village headmen, while in the rainless summers we slept on the canal banks, and during the day accepted the hospitality of the villagers. Travelling as we did, with but few attendants, and visiting the same individual once in two or three years, we were no serious source of expense to village sheikhs, while the knowledge we had of their wishes and difficulties was of the greatest value to them as well as to ourselves. It was this knowledge which enabled us to keep some check on the all-powerful watchmen on the spot and the all-powerful Arabic clerks in our head offices. Unless one frequently meets and converses privately with the village authorities, it is impossible to understand how the power of the Arabic clerks can be controlled. The whole of the correspondence is in literary Arabic, which the Inspector as a rule cannot read and which he would not have the time to read if he could. The consequence is that what he really hears is a rough epitome in ordinary spoken Arabic of long, meandering letters. Now, if the Inspector has spent much time in the district and seen many men, the Arabic clerk is afraid to take many liberties with the text of the letters, lest he stumble into a pit; but if he knows that the Inspector has scarcely spoken to anyone, he is as completely master of the situation in the office as the watchman is on the canals. Scores of rules and procedures may be invented, but the only remedy for the control of the irrigation passing out of the hands of upright chiefs into those of unscrupulous subordinates is steady and persistent inspection of the works and friendly intercourse with the village sheikhs and fellahin inside their own homes or in their fields where they can speak freely and openly.

During the two years that the Land Tax Adjustment operations lasted

the Director General spent every day and slept every night in the fields and villages. He conversed with the representatives of every individual village between Wadi Halfa and the Mediterranean Sea, in the grounds of the village itself, and dispensed with most of the correspondence which more often than not darkens counsel with words. Every one of the ten commissions knew that it was liable to inspection at any minute, and this knowledge was a great spur to their keeping up their inspection to the full measure of their ability. For it must never be forgotten that if the head slackens his inspection, every subordinate does the same. "Does a fish begin to go bad at the head or at the tail?" is a sound Arabic proverb.

Inspectors to-day are often accused of being overbearing and having little patience with criticism. It is not easy to be patient with men whose difficulties have not been seen on the ground. Many things seem unreasonable in an office which would appear reasonable enough on the spot. It is for this reason that every Inspector of Irrigation should welcome all criticism of his works, be it by friend or by foe. It needs courage and conviction to criticise a Government so autocratic and powerful as that of Egypt in the field of irrigation. It was Mohamed Ali who said, "Give me regulators at the heads of the canals, and I am master of Egypt"; and he had reason on his side. Perpetual incense and praise do one no good. Most of it is interested. It is again Solomon who advises us to beware of the friend who wakes up early in the morning to bless us with a loud voice. He only too often encourages us to make fools of ourselves.

If, owing to the pressure of office work, Inspectors of Irrigation can no longer be in touch with the country as they were over twenty years ago, it might be possible for the irrigation circles to be divided into zones according to their irrigation requirements. Each zone might consist of twenty or twenty-five ordinary villages, from among which the landowners would choose a representative man for each zone, who would be in a position to converse freely and openly with the Inspector and keep him in touch with the wishes and requirements of the countryside. During the Land Tax Adjustment Operations, Nubar Pasha insisted that the landowners should choose their own representatives without any kind of official interference. It was a matter of surprise to everybody in Egypt that the men they chose were so exceptionally good. Many of them were quite poor fellahin, but they had sterling qualities which their neighbours had recognised. If the people were left to themselves to elect representatives whose tenure of office would last one year, the Inspectors might find themselves dealing with really representative men in the flesh, and not with what are only too often the Arabian Nights inventions of their Arabic clerks. We have seen in paragraph 171 how the peasantry in the irrigated parts of Spain, in years of scarcity, choose their own Dictators whose orders

are obeyed without demur; and that they seldom choose a bad representative.

Knowledge of English and French is making great strides in Egypt to-day, and Inspectors have one advantage unknown to their predecessors. They can correspond demi-officially with their subordinates in a European language on a scale which was impossible some years ago. Of course indulgence in a demi-official correspondence in addition to the official Arabic literature means that an officer has to give the whole of his time to his work; but it may safely be said of irrigation, that if one is not prepared to devote himself to it body and soul, he has mistaken his profession.

180. **Land, Water, and Manure Taxes.**—Of all the countries on the face of the earth Egypt has the best system of land and water taxation combined. The cause of Irrigation can always lean with confidence on the arm of her eldest daughter. The taxation is as easy to understand as it is effective in operation. Our neighbours in Turkey and Cyprus are in the Stone Age of land taxation, while India has a system so complicated that where Egypt uses one word—*music*,—India employs the language of the prophet Daniel and says *cornet*, *flute*, *harp*, *sackbut*, *psaltery*, *dulcimer*, and *all kinds of music*.

In Turkey and Cyprus the tithe is still annually measured and taken as it was when the earliest inhabitants of the lower Euphrates Valley first conceived the idea. No great advancement in agriculture is possible with the tithe. Those who exert themselves and improve their lands at their own expense pay heavy taxes, while the lazy and indifferent pay light ones, and the hopelessly idle go off scot-free. The commutation of the tithe to a fixed land tax which is changed every thirty years, as in India and Egypt, is the first step to real progress. The tax is fixed and known, and the really industrious enjoy the full benefit of their toil, while the lazy and careless have to pay their fair share of the taxes. Egypt, however, has advanced beyond this stage. If a parcel of land receives basin irrigation, it pays one category of land and water tax, whether the owners reap their single harvest or whether they double it by their own industry. If it receives perennial irrigation, it pays another category. No Government official is interested in irrigating a large area of land with a minimum of water. No cultivator puts off irrigating his land to the last moment and hurts his crop in the hope of evading the water tax. It is Mr Beresford's opinion, with his wide experience of India and Egypt, that the crops in India do not, as a rule, receive a sufficiency of water. The water is wire drawn. In India they pay a land tax, an owner's tax, an occupier's tax, and a water tax; and the whole of these together come to practically the tithe of the gross produce. In Egypt they pay a proportion of the rent, which is simplicity itself. (In the ordinary conditions of Eastern agriculture, the tithe of the gross produce equals one-third of the land rent.) It is

extraordinary that in India some strong man does not imitate the wisdom of Egypt and have a fixed tax which would combine all the different taxes. This beneficial reform might be initiated in the nearly rainless parts of Sindh and the North-western Punjab, and then gradually introduced over the whole country.

Enjoying the advantage of a single land and water tax, Egypt conceives its projects in a broad and statesmanlike spirit. Note is taken of the fact that the whole tract will benefit, though all do not benefit equally; still, if a man's neighbours become richer and more prosperous, he too benefits by their greater power of spending money and paying higher wages. The Government, moreover, does not consider only the direct gains from taxation; it considers the increased transport on its railways, the increased import of necessaries, the increased use of duty-paying luxuries like tobacco, the diminished losses of revenue in years of scarcity, and the improved well-being of the population. India, as a rule, does exactly the opposite. With rare exceptions, it calculates the expenditure and revenue of its projects on commercial lines, just as though it had only the direct taxes to deal with; and, on this account, rejects project after project in the tracts where they are most needed and carries them out where they pay best whether they are needed or not. Read carefully the report of the Famine Commission, of which Sir Colin Scott-Moncrieff was President, and this spirit is in evidence everywhere. Millions upon millions are spent in the Punjab because there the profits are enormous, while in the famine-afflicted Deccan little is done because the financial aspect of the question is not encouraging. The policy would be sound if the profits of the Punjab works had been all ear-marked for the works in the Deccan which could scarcely pay their way; but they were not. Each tract was taken on its own financial merits, with but rare exceptions. Now, if there had been but a single tax in India as in Egypt, we should have seen works carried out in the Deccan on the same scale as in the Punjab. The broad Egyptian spirit would have been in evidence everywhere.

But Egypt to-day is not going to stop at a land and water tax. It is contemplating a manure tax. Manure is as necessary for the land as water, and the Government is going to manufacture manures and can issue them to the agricultural population. As sources for these there are available the limestone and the nitrate and phosphate deposits in the Southern deserts. Distributing water and manure, they will be able to put the taxes into a third category and make all pay for land, water, and manure together. The Agricultural Department knows the minimum requirements of the land, and fixed quantities of manures could be distributed from central depôts to the whole country. Those who wished to purchase more than the regulation allowance could do so, just as a man who has basin irrigation and pays for it, can dig a well in his field and enjoy perennial irrigation at his own

expense. If, at the same time that the Government distributes its manures, it keeps in the forefront of its projects the provision of an abundance of the fertilising water of the Nile flood, Egypt will enter upon an era of prosperity such as neither Rameses nor Thothmes ever conceived.

Why should not India do the same? It could do it in many ways, once it had decided to simplify its taxes. It could directly procure nitrates with the aid of the water-power of the Himalayan torrents. It could halve the taxes on all lands under leguminous crops and so encourage the storing of nitrogen in the soil. It could take advantage of the fact that the first heavy falls of monsoon rain on the dry and friable soil fills the rivers in their early stages with water which is in great part manure. By building suitable works on the rivers and their tributaries, it might lead these waters over the poor worn-out soils and give them a new lease of life. All these projects would not pay as irrigation enterprises, but they would pay, a hundredfold, indirectly. Famine expenditure would be reduced beyond recognition, and the successful completion of our project would show the way for developments unthought of to-day. These would be no visionary projects: they would be sound investments.

Even that poor and worn-out island of Cyprus, where thousands of years of cultivation of cereal crops have robbed the soil of nearly the whole of its phosphate, might with superphosphate renew its fertile youth. A fixed land and manure tax in the place of the primitive tithe would bring back the days when Cyprus was a granary, and famous for the productiveness of its soil.

We have no intimate knowledge of land taxation in England; but one of us remembers well that, on the termination of the sale of the £11,000,000 of land by the Daira Sania Company, he spent a considerable amount of time in examining into the values and conditions of the properties for sale in the eastern counties, and conceived the idea of forming a Daira Sania Company in England for the purchase, improvement, and eventual sale of the land in allotments. When the project was put before the able financier who, in the disposal of the lands of the Daira Sania Company, had laid it down as a rule that the board of a land company owed duties to its neighbours as well as to its shareholders, he replied that if England enjoyed rates fixed for thirty years, like the land taxes of Egypt, such a project would be sound, but under existing conditions, the profits would all be swallowed up in paying the rates of the district. Agricultural prosperity in England even might follow sound land rating on the wise lines adopted by Egypt.

181. **Land Reclamation.**—In CHAPTER VIII. we have given the matured opinions of many land experts in Egypt on the reclamation of the waste lands of Lower Egypt. The process to-day is well understood, and success should be inevitable; yet very few land companies have been a

success. The failures at first were due to ignorance; but to-day there is an established procedure, well known and easy to follow, and yet success on the ground has not been so simple as it has been on paper. We consider it of practical value in this chapter on *Administration* to give our reasons why land reclamation companies in Egypt have so seldom been a success.

(1) First and foremost we may say that since 1905, owing to competition, companies have paid a price for their land which was far beyond its value. Waste land, as white as Gehazi after he was struck with leprosy, has fetched £20 per acre, and land yielding £2 per acre per annum has been valued at £60. If absolutely waste land cannot be purchased at from £5 to £10 per acre, according as it is rough or level, it will be difficult to make a success of land reclamation. Taking £10 per acre as the value of level waste land giving no return, the true value for land under cultivation and yielding some kind of crop is £10 plus fourteen times the annual net profit. Thus if a plot of level land is giving a net return of £2 per annum, its value to a reclamation company is $\{£10+(2\times 14)\}$ or £38 per acre. Such land, if provided with good irrigation and drainage and well managed, should yield £4 per annum.

(2) Land has often been purchased which has had a very poor supply of water for irrigation. Very many of the Government canals to-day have a section which does not allow them to carry enough water in flood to put a reasonable part of the estate under rice and annually refresh the soil. Moreover, for washing salts out of the soil, liberal irrigation in winter, when the Nile has abundance of clear water, is of great value; but unfortunately the Irrigation Department shuts off the canals for six weeks and upwards at this very time, and this golden opportunity is lost to the agriculturists. When the canal supply does come, the clover, barley, and other winter crops are so thirsty that it is as much as one can do to keep them alive, leave alone wash salts out of the waste lands during the winter. Then again the reduction of the red water of the Nile flood, which has gone on steadily for years, has told heavily against the poor lands renewing their strength. Abundance of red water refreshes and renews just as clear water washes out the salts. In flood and winter the canals should be carrying maximum supplies, while only too often they are carrying very little. This water comes from heaven and is not stored in reservoirs, and the day it is poured freely over the lands under reclamation, the reclamation will not be retarded as we see it to-day.

(3) Drainage difficulties have often stood in the way of successful land reclamation. If from the very beginning the Government had, in Mr Dupuis' words quoted on page 473, looked on its drains as a means of removing the drainage water poured into them by private drains, whether such water were lifted or flowed naturally, the Government drains would

have been as independent as the canals where water for irrigation has to be lifted by the agriculturists when they cannot obtain it by free flow. Very many reclamation projects have been thrown back by the managers waiting for this deep drainage by gravitation, which was possible to-day and impossible to-morrow and could never be depended on. But not only has this effort of the Government to give deep drainage by gravitation retarded land reclamation where the managers have waited for it in vain, it has been a great drawback to those who have erected pumps and have had to stop pumping for long intervals of time at critical moments because the engineers were prohibiting all ingress of water into the drains during their efforts to lower the water surface by drastic clearances. It has often happened that land under reclamation has had its irrigation water cut off to allow of the Government canals being cleared, and when at last the canals have begun running, the drains have not been sufficiently cleared to allow of their being used. Between canal and drain clearances many an estate has been deprived of its opportunity of washing and lost nearly a whole year, and that more than once. If capacious drains were kept running and canals kept full of water, land reclamation companies could well look after themselves. More delays and disappointments have been caused by these mischances than by almost any other cause.

(4) Many land reclamation schemes have miscarried owing to the managers putting off the erection of pumps and hoping that shallow drainage by free flow would do what it can never do.

(5) Pipes of a suitable length which allow the surface water of the fields to enter the drains without breaching into them and choking them with deposit have not as a rule been employed. The necessity of these is coming prominently forward to-day, and it is owing to the shirking of the solution of this question that many estates have not been reclaimed as they should have been. Owing to it, many sections have given better yields of cotton in their third and fourth year than in any subsequent year. Land reclamation is one thing, keeping the drains deep and free of deposit at all times is another, and the latter is as important as the former. It is unfortunate that more money has not been spent in the substitution of covered pipe drains for open trenches in all the tertiary drains of reclaimed lands where the soil is stiff clay. The high prices paid for waste land have been at the bottom of the harmful economies on this head.

(6) If the Mosséri system had been known six years ago in the way it is known to-day, land reclamation would have had better results to show in every estate where the soil is stiff clay.

(7) It is difficult to introduce the Mosséri system on a plot of land already drained in the ordinary way, since the shallow surface drain has to lie on the further side of the deep infiltration drain, and there is not as a rule room for it along the roadway which skirts the latter.

(8) The pumping of drainage water is a new enterprise in Egypt, and it was not at first recognised that careless land agents could retard reclamation by periodically stopping the pumps for long intervals of time and allowing the water to accumulate to a great height in the drains before it was pumped. Many delays in reclamation were due to this. To-day this is not tolerated on any well-managed estate.

(9) The presence of large numbers of careless, shifty Arabs in the waste lands, has also retarded reclamation. Egyptian fellahin do not readily leave the congested tracts where they live, but their presence in fair numbers on any estate under reclamation is one of the first steps towards prosperity. Sufficient inducements have not as a rule been offered to these men. The high prices paid originally for the land has been at the bottom of most of these difficulties.

(10) Localities where Egyptian clover (berseem) cannot be readily disposed of have also not shown as good results as they otherwise would.

(11) Companies which have sold half-reclaimed land to the fellahin, and extracted their pound of flesh on the instalment system, have done much harm to the cause of land reclamation. They have earned the hostility of the very men who alone can make the works a success, and they have induced the Government at times to take up an unfriendly attitude to all the companies.

(12) And last, but by no means least, speculators who have purchased land, not really to reclaim it, but to sit on it and wait for a rise and then sell it at a high price, have been a positive curse in Egypt, as they have been in every country on the face of the earth. It is extraordinary that legislation has not been introduced to brush this plague out of the country. Lower down we propose a solution for this difficulty in the waste lands.

The Government to-day is itself undertaking the reclamation of selected tracts of waste land and employing State funds for the purpose. The selected sections are levelled, provided with watercourses, drains, and pumps, have villages erected on them, are divided into five-acre lots, and then handed over to the fellahin. In the first settlement at Biela the new proprietors are not landless fellahin from the congested districts but fairly substantial men from the next village. Though they own no arable land, they are credited with possessing houses and working cattle and milch kine of their own. In future settlements men from the congested districts may be brought down. Of course when a government undertakes such work it is impossible to tell what such a scheme costs, as large works of construction or maintenance are always on hand in the neighbourhood and the expenses are not necessarily kept in the form in which a company is forced to keep them when it undertakes nothing but the works themselves. Moreover, the Government can and does take as much

water as it pleases, is not tied down to drainage pumps of a certain size, pays prices for labour, and can use reservoir water on a scale which a company could not or would not be allowed to. Economies on this head are out of the question with Government undertakings. Logically it is scarcely fair to take part of the taxes of the community and hand them over to favoured individuals, when the very men who are paying the taxes are being injuriously affected by this procedure. It is for this reason, knowing that the principle of making the fellahin proprietors of the lands is one of the soundest in the world, and is one which was strongly advocated by one of us in the early days of the Occupation (see page 455), we propose a method of procedure, by following which, the State will spend no public money; the Irrigation Department will be able to practise every reasonable economy in the distribution of water and drainage privileges; and we shall secure fellahin landowners with an influx of foreign capital into the country.

Let plots of 10,000 acres of waste land, which are worth £50,000 apiece, be handed over without payment of any kind to approved companies, to level, drain, and provide with villages and pumping installations. Let it be assumed that half the land will eventually be in the possession of the fellahin and half in that of well-to-do landowners. When reclaimed, let the company hand over a quarter of the land free of charge to fellahin from the congested districts, who will have power of option on another quarter at prices fixed beforehand. With the land taxes moderate at first, but rising slowly and assuredly, it should be possible to keep out the land speculator, who could not afford to sit idle while the taxes were rising automatically. In this way we think it should be possible to save the funds of the State for public works properly so called, to insure fellahin proprietors, and at the same time introduce foreign capital and enterprise into the country. Just as companies are not suited for the control of large public canals and drains, so Government officials who control these public works are not qualified to distribute fairly the water and drainage privileges of the State to private landowners and to estates under their own management, at one and the same time, when both are drawing from the same canal and discharging into the same drain.

APPENDICES.

APPENDIX I.

EVAPORATION ON THE WHITE NILE.

In paragraph 141 we promised to return to this matter, of fundamental importance, since on it water storage in the valley of the White Nile may entirely depend for success or failure. Consider the volume of water in the trough between Malakal and Khartoum, and let us make up its balance-sheet between two given dates. It will be augmented by the total inflow at Malakal and depleted by the outflow at Khartoum between these dates, and this irrespective of whether the same water flows out as flows in. It will be diminished by the total amount of water evaporated and by the total amount lost from infiltration which, in the White Nile, may be entirely neglected. It may be increased by rainfall or the flow of tributaries, but these contributions are negligible in the dry season. The excess of gain over loss will go to raise the water surface in the reach considered.

The volume lost by evaporation will be measured by the evaporation per day multiplied by the number of days and the area of the water surface, or eTA, and for A we may write LB, where L is the distance from Malakal to Khartoum and B the mean breadth. Evaporation then causes a total loss of eTLB. The amount of water flowing in is q_1T, where q_1 is the mean volume discharged per day at Malakal during the interval; and that flowing out is q_2T, where q_2 is the mean volume discharged at Khartoum during the same interval. The increase of the volume is measured by the mean change of the cross section—S, say—during the time, multiplied by the distance L. Hence we have the equation

$$q_1\mathrm{T} - q_2\mathrm{T} - e\mathrm{TLB} = \mathrm{SL}.$$

In this equation we may find by observation all the quantities except e, and so may find e. To do this we must have the mean discharges at the two sites, the distance between them, the mean breadth, and the mean change of sectional area during the interval. These are exhibited in the following table for periods from 1st January to 30th April 1912.

The first and second columns are self-explanatory. The third gives the discharges corresponding to the mid-date of the period, at Malakal. The curve of discharges at Malakal is on the whole concave upwards, and the value for the mid-date will be less than the true mean. At Khartoum the corresponding curve is still more curved. The result will be that $q_1 - q_2$ is on the whole too large, and the deduced evaporation also slightly too large at this time. An examination of the figures shows that in February the deduced evaporation may be expected to be too small; March appears to resemble January, but April is about right. The figures in the third and fourth columns are in millions of cubic metres per day.

TABLE 276.—COMPUTATION OF EVAPORATION ON THE WHITE NILE (1912).

Periods.		Days in Period.	Mean Daily Discharge, in millions of cubic metres.		Mean Breadth at Beginning, in metres.	Sectional Area at Beginning of Interval, in square metres.	Change of Area in the Interval, in square metres.	$(q_1 - q_2)$T.	SL.	Difference $= e$TLB $=(8)-(9)$.	TLB.	e in milli-metres.	
			Malakal.	Khartoum.									
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Jan.	1–10 .	10	68·5	76·9	934	2222	– 294	– 84	– 243	159	7·3	21·8	
	11–20 .	10	62·8	66·7	829	1928	– 206	– 39	– 170	131	6·6	19·8	18·1
	21–31 .	11	58·6	62·8	777	1722	– 161	– 46	– 133	87	6·8	12·8	
Feb.	1–10 .	10	54·8	58·1	722	1561	– 86	– 33	– 71	38	5·8	6·5	
	11–20 .	10	52·0	53·9	693	1475	– 82	– 19	– 68	49	5·6	8·8	10·4
	21–29 .	9	50·4	47·4	660	1393	– 60	+ 27	– 50	77	4·8	16·0	
March	1–10 .	10	48·1	44·1	636	1333	– 37	+ 40	– 31	71	5·1	13·9	
	11–20 .	10	45·9	42·2	600	1296	– 63	+ 37	– 52	89	4·9	18·2	14·5
	21–31 .	11	44·6	40·5	583	1233	– 18	+ 45	– 15	59	5·2	11·3	
April	1–10 .	10	43·2	41·0	550	1215	– 31	+ 22	– 26	48	4·5	10·7	
	11–20 .	10	43·8	41·1	533	1184	– 2	+ 27	– 2	29	4·4	6·6	8·1
	21–30 .	10	41·6	40·2	538	1182	– 21	+ 14	– 17	31	4·4	7·0	
May	1 .	...	...	...	527	1161	...	...	...	Mean	...	12·8	

The fifth column gives the mean breadth of the river on the first day of the period, as deduced from measurements on ten representative sections from Malakal to Gordon's Tree (Khartoum). The simple arithmetic mean was taken, in place of weighting each gauge by the length of that part of the river which it represented: the error cannot be large. The sixth column gives the mean sectional area in square metres, at the beginning of each interval, and is obtained in a similar manner to the preceding column. The following column gives the change of sectional area or S in the interval. The eighth column gives the excess of the volume in millions of cubic metres entering at Malakal over that leaving at Khartoum—or where the numbers are negative, the defect. Following it is given the average depletion of the trough in each interval, in millions of cubic metres. The depletion of the trough accounts for the excess of Khartoum over Malakal discharge and the total loss from evaporation. The difference between the quantity by which the trough is depleted, and the balance of discharge, therefore, gives the total loss from evaporation which appears in the tenth column. The average breadth during the interval is taken to be the mean of those at the beginning of that and the next interval and, multiplied by the time T and the distance from Malakal to Khartoum, gives the penultimate column, in units of milliards of square metres. The last column gives the daily evaporation in millimetres per day over the water surface. It will be seen that the figures for January appear to be high, those for February too low, and those for March possibly too high; but it should be remembered that when the river is up, as it is in January, it covers to a slight depth great extents of sandbanks and marshy ground, and the rate of evaporation will then be raised over the shallow flats, and it should not be forgotten that the individual figures are possibly affected by the various errors that may arise in discharge measurements. The mean 12·8 millimetres is probably as close as we can get to the evaporation from the river surface at this season in 1912. Wind force in the Sudan was below average for each of the four months, and as the variation of the wind is the chief controller of the variation of evaporation, it is likely that the average evaporation exceeds the above figure and may be put at 14 millimetres per day. It is also likely that the evaporation from the northern half exceeds that from the southern half, and may be taken as 15 millimetres per day at this season. (See pp. 77, 278, and 280.)

APPENDIX II.

DESCRIPTION AND STRENGTH OF EGYPTIAN STONES, AND STRENGTH OF EGYPTIAN MORTARS.

(Appeared originally in *Perennial Irrigation and Flood Protection*, 1904).

DESCRIPTION AND STRENGTH OF EGYPTIAN STONES.

THE building stones in Egypt are syenite, Nubian sandstone, and limestone of the Tertiary formation. Specimens of the different classes of stone were sent to Professor Hudson Beare, of University College, London, to be tested, and this appendix is an epitome of his report. His calculations were all made in pounds and square inches, which have been reduced to kilograms and square centimetres.

Limestone from Old Cairo.—This is a dense crystalline stone, slatey grey, greyish white and creamy in colour; the greyish white was the densest and strongest.

Limestone from Tura.—This is a semi-crystalline stone, not dense, creamy in colour; the denser the stone the stronger.

Black Diorite from Aswan.—A micaceous diorite with rather fine crystals.

Red Syenite from Aswan.—A granite with large pink flat crystals of felspar.

Nubian Sandstone.—This is a coarse silicious sandstone, with little cementing material, of a whitish colour. The denser the stronger.

From each block of Old Cairo and Tura limestone and Nubian sandstone nine cubes were sawn out, and the bed faces of each cube rubbed smooth and parallel. These were all $2\frac{1}{4}$-inch cubes, except from one block from Old Cairo, which had sides of 3 inches.

From the syenite and diorite blocks rough pieces were cut out by chisels and wedges and dressed to size by chisels, and then finally rubbed down to 2-inch cubes.

The following tests were made : density, absorption of water, crushing strength.

Density and Weight.—Each specimen after thorough drying was carefully weighed, its volume calculated, and therefrom its density.

Absorption of Water.—Two specimens of each block were, after weighing, immersed in distilled water at air temperature, and kept there for seven days. They were then taken out, at once wiped dry and reweighed. The gain of weight represents the water absorbed.

Crushing Strength.—The bed faces of the cubes were strickled over with a thin layer of plaster of Paris; these were then rubbed quite smooth and parallel, and in testing, these faces were applied directly to the dies of the machine. All the cubes were tested when quite dry. The load was gradually increased from zero to

crushing load; if any cracking occurred at lower loads than the actual breaking load, the fact was noted.

1 lb. per square inch = ·07 kilogram per square centimetre.
1 kilogram per square centimetre = 14·2 lbs. per square inch.

TABLE 277.—CRUSHING LOAD OF EGYPTIAN STONES.

Class of Stone.	Weight of a cubic metre in kilograms.	Crushing Load in kilograms per square centimetre.	Absorption of Water per cent. of Dry Weight.	Remarks.
Limestone from Old Cairo.	2560	1045	·80	All except the fifth were $2\frac{1}{4}$-inch cubes. The fifth was a 3-inch cube. The second specimen had crystalline hollow spaces in interior.
	2560	801	1·09	
	2580	1121	1·27	
	2590	1051	·73	
	2590	1068	...	
	2760	1245	·75	
	2610	1056	·93	Mean of 18 cubes.
Limestone from the Tura quarries.	2310	367	4·27	All $2\frac{1}{4}$-inch cubes.
	2330	523	4·35	
	2340	589	4·02	
	2430	566	2·36	
	2490	708	1·40	
	2380	551	3·28	Mean of 15 cubes.
Black diorite	2790	1279	·25	All 2-inch cubes.
	2810	1348	·12	
	2800	1313	·19	Mean of 5 cubes.
Red syenite	2640	1307	·13	All 2-inch cubes.
	2640	1530	·26	
	2640	1418	·20	Mean of 6 cubes.
Nubian sandstone	1850	152	11·16	All $2\frac{1}{4}$-inch cubes.
	1860	112	9·91	
	1890	202	10·32	
	1950	264	9·87	
	1880	183	10·31	Mean of 12 cubes.

Old Cairo Limestone.—The heaviest block had the greatest crushing strength. The cubes began to crack at loads which were 50 per cent. of the crushing loads, differing very much in this respect from the granites. The water absorbed was small but distinct.

Tura Limestone.—The densities vary from 2·31 to 2·49, and the crushing

strength from 367 to 708 kilograms per square centimetre. The denser the stone the stronger. The densest stone approaches those from Old Cairo. The greater the density the less the water absorbed. The cracking load is not much under the breaking load.

Black Diorite from Aswan. Red Syenite from Aswan.—The syenite is less dense than the diorite, but it is distinctly the stronger stone. These granites are practically non-absorbent. The dampness of surface causes the trifling additional weight.

The cracking and crushing load is one.

The diorite is very difficult to work and refuses to split at the wedge lines. The syenite is easy to work and splits along the wedge lines.

Nubian Sandstone.—The denser blocks are *much* stronger than the less dense. The cracking and crushing weight is one. This stone is exceptionally poor, and absorbs an extraordinary quantity of water. The stone is more like an English oolite than a sandstone. A series of 4-inch cubes when crushed gave a compressive strength over 50 per cent. in excess of the $2\frac{1}{4}$-inch cubes.

The coefficients of elasticity of Old Cairo and Tura limestone are 500,000 and 350,000 kilograms per square centimetre respectively—the same as hard English dolomites.

STRENGTH OF EGYPTIAN MORTARS.

In order to test the strength of the hydraulic mortars of Egypt, a continuous series of tensile experiments has been made. The tensile tests were made with briquettes of a minimum section of 1 square inch.

The limes tested were the following:—

Fat *Cairo* lime from the Batn el Bakkar quarry.

Fat *Silsila* lime from the Raghama quarry, of a *white* colour.

Fat *Silsila* lime from the Raghama and Fatèra quarries, of a *dark* colour.

The limestone was burnt and slaked, and then used fresh. The puzzuolana was made from rich black Nile deposit, burnt to a dark red colour, and then ground and sifted. It was likewise used fresh. The sand was quartz sand from the desert. The puzzuolana classed as coarse was sifted through a sieve of 400 meshes to the square inch, and that called fine was sifted through a sieve of 900 meshes to the inch. The coarse sand passed through a sieve of 400 meshes to the inch, but was retained on a sieve of 900 meshes to the inch. The fine sand was sifted through a sieve of 900 meshes to the inch.

The slaked lime and puzzuolana were mixed dry in the proper proportions and then had water added to them. A portion was taken from the mass, stirred in a mixer for two hours, and then made into briquettes. The briquettes were left in the moulds for twenty-four hours, then put into damp sand for six days, and finally into water for six months less a week. At the end of six months from the day of moulding they were broken. The mass of the mortar was put into metal troughs and kept wet, and briquettes were made daily from it till it was expended. In some cases eighteen days elapsed between the making of the mortar and the moulding of the briquettes.

Twelve briquettes were always made; six were broken after six months, and the rest will be broken when twelve months have elapsed. So far we have broken after twelve months none of the briquettes made of the good proportions and good

ingredients mentioned in the table; but judging from the results with the inferior mixtures, we may fairly anticipate a gain of 50 per cent. in the strength of the mortars after twelve months as compared to the six months' tests.

The best proportions for the ingredients have been found to be as follows :—

1 part by measure of slaked fat lime.

$1\frac{1}{2}$ part by measure of fine puzzuolana.

1 part by measure of coarse desert sand.

By way of comparison, briquettes were made of the well-known Theil lime from France, of which especially good specimen bags were ordered. This lime is so well known and appreciated that the comparative tests prove conclusively that in Egypt we have the materials for manufacturing a really first-class hydraulic mortar.

Hydraulic mortar made of the Cairo lime is stronger if used ten days after manufacture than if it is used fresh. Both the Silsila lime mortars are distinctly stronger, however, if used fresh than if they are allowed to stand even for twenty-four hours. These latter mortars decrease in strength steadily as they get older.

Briquettes were also made of mixtures of 4 lime, 8 sand, and 1 cement, and 10 lime, 5 sand, and 1 cement. These were the proportions of the mortars used at the new Puentes and Villar dams in Spain (mentioned in Appendix I. of the Report of 1894). It is very evident from the tests recorded at the bottom of the table that the Egyptian limestones are not all suited for mortars made of these ingredients.

Finally, briquettes were made of finely pounded unburnt clay; sifted through sieves of 5000 meshes to the inch, and mixed with lime and sand, or lime alone. The best proportion was 2 lime, 1 sand, and 1 unburnt clay; but the tests recorded at the bottom of the table prove that the use of unburnt clay is attended with risks, and results in a mortar of mediocre strength.

[TABLE

TABLE 278.—TENSILE STRENGTH OF MORTARS IN KILOGRAMS PER SQUARE CENTIMETRE.

Briquettes Tested Six Months after Manufacture.

(Multiply by 14·2 to obtain lbs. per square inch.)

Age of Mortar in Days.	Neat Theil Lime from France.	1 Theil Lime, 3 Coarse Sand.	1 Theil Lime, 3 Fine Sand.	1 Cairo Lime, 1½ Puzzuolana, Fine.	1 Cairo Lime, 1½ Puzzuolana, Coarse.	1 Cairo Lime, 1½ Puzzuolana, Fine, 1 Fine Sand.	1 Dark Silsila Lime, 1½ Puzzuolana, Fine.	1 Dark Silsila Lime, 1½ Puzzuolana, Coarse.	1 Dark Silsila Lime, 1½ Puzzuolana, Fine, 1 Coarse Sand.	1 White Silsila Lime, 1½ Puzzuolana, Fine.	1 White Silsila Lime, 1½ Puzzuolana, Fine, 1 Fine Sand.
fresh	24	16	8	15	16	16	21	20	14	20	18
1	...	...	...	14	16	18	19	14	12	14	16
2	....	...	...	12	19	17	17	14	9	12	13
3	...	...	...	17	17	21	15	14	9	16	14
4	...	...	...	15	17	19	16	12	11	17	14
5	...	...	...	15	17	17	17	12	12	16	14
6	...	...	...	12	17	17	19	...	12	15	13
7	...	...	...	12	15	17	18	...	...	18	13
8	...	...	...	15	14	20	13	...	...	15	13
9	...	...	...	15	16	20	11	...	...	12	12
10	...	...	...	16	17	23	11	...	...	12	12
11	...	...	...	...	...	...	12	...	...	14	12
12	...	...	...	...	...	...	14	...	...	16	11
13	...	...	...	...	...	...	12	...	...	14	
14	...	...	...	...	...	...	11	...	...	15	
15	...	...	...	...	...	...	11	...	...	13	
16	...	...	...	...	...	...	12	...	...	12	
17	...	...	...	...	...	...	12	...	...	14	
18	...	...	...	...	...	...	12				

Briquettes of 10 lime, 1 cement, and 5 sand were broken at 8 kilos. per square centimetre.
,, 4 ,, 1 ,, 8 ,, ,, 7 ,, ,,
,, 2 ,, 1 sand, and 1 unburnt stiff clay were broken at 10 kilos. per square centimetre.

In the case of the last briquettes, the mortar had to be put into the moulds immediately after it was made, as the least delay resulted in the briquettes either cracking or melting away when placed in water.

APPENDIX III.

A NOTE BY DR SCHWEINFURTH ON THE SALT IN THE WADI RAYAN.

(Appeared originally in *Perennial Irrigation and Flood Protection*, 1894.)

REPORT ON THE SALT* IN THE WADI RAYAN RESERVOIR.
By G. Schweinfurth.

An exact valuation of the amount of salt which will be contained in this reservoir, when the water has risen to a height of 27 metres above the Mediterranean, cannot be made, owing to the absence of information on some of the following points:—

Data wanting

1. The percentage of salt in the soil of the reservoir bed.
2. The thickness of the salty strata of the bed permeable to water.
3. Mean specific gravity of the desert soil of the reservoir and the feeder canal.
4. The time of filling.
5. The dimensions of the canal and the area of the lands flooded by the canal.
6. The percentage of salt in the desert soil traversed by the canal, and the extent of the inundation.
7. The thickness of the strata permeable to water in the bed and sides of the canal.
8. The percentage of salt in the Nile deposits traversed by the canal in the Nile Valley.
9. The thickness of the strata permeable to water in this last canal.
10. The mean specific gravity of the Nile deposits traversed by the canal.
11. The volume of subsoil water which will enter the canal by infiltration, and the percentage of salt in it.

To find an approximate value we can, however, substitute for the exact data approximate ones, based on observed facts and obtained tentatively.

Numbers 4 and 5 are of the greatest importance in your present inquiry. I shall show further on that if the filling lasts seven years, it will in no way compromise either the Nile or the cultivation, but if the filling is slow the water of the reservoir will be unfit for irrigation.

Agricultural Axioms.—Once salt is contained in the water of the reservoir, there it will remain for ever unless there is outflow. This is a fundamental truth in Egyptian agriculture, which is nothing but a continued fight against salt. If there is no outflow, the constant entry of Nile water can in no way remedy this state of

* By "salt" I always mean "Chlorure of Sodium."

PLAN OF

PROPOSED WADI RAYÂN ESCAPE.

Scale $\frac{1}{675.000}$

All R.L.s in metres, above + or below − mean sea.

Desert

affairs, and the salt will accumulate owing to evaporation all the years that the reservoir is being filled.

Salt is unalterable.—Salt (chlorure of sodium) undergoes no chemical transformation in contact with Nile water, or with any of the substances the water contains in suspension or solution. One other peculiarity of the salt is the invariableness of its degree of solubility under different temperatures.

Earth and Rock Specimens should be analysed.—To obtain the percentage and specific gravity of the salts contained in the desert soils in the reservoir a special inquiry should be instituted.

A large and varied number of specimens should be analysed chemically to find the mean quantity of the salt.

The surface of the Wadi Rayan, as compared with other parts of the desert, contains a large quantity of salt, because the rainfall finds no escape from the depression, and concentrates there the salt of the adjacent lands. The efflorescence, also, which is always more active where the ground is alternately wet and dry, tends to augment the quantity of salt at the bottoms of depressions which have no outlet. During my visit in 1884 I myself saw quantities of salt at the surface of the ground in the Wadi Rayan. There is a single spring of sweet water, but it becomes brackish after flowing a short distance, and gives birth to scarcely any vegetation.

Limits of Cultivation in Salted Lands.—In Egypt it has been found by observation that certain wild and cultivated plants can support 2 per cent. of salt in the soil, provided that the latter is perpetually humid. Under these conditions of perpetual humidity the salt may rise to 4 per cent. before rendering the soil absolutely sterile. On the contrary, a soil which is alternately wet and dry is rendered sterile by 1 per cent. of salt.

Almost all the desert soils of the Tertiary formation in the interior of Egypt are naturally uncultivable without washing and draining. It is for the same reason that they are generally devoid of wild plants.

Natural Drainage in the Desert.—The *high limestone plateaus* of the eastern desert above 1000 metres in height, the Mediterranean *littoral*, and the *beds* of all torrents, are an exception. These lands have lost the salt which is contained in all limestone strata in clay strata, and on the desert plains. The more abundant winter rains in the two first instances, and in the case of the third the concentrated drainage of the rare falls of rain, have produced this result.

The Maximum Percentage of Salt possible in the Desert Soils.—In accordance with these facts one may roughly estimate, without fear of exaggeration, the maximum quantity of salt in the desert soil as 2 per cent. I shall use this figure in my calculations, and I am confident it will never be surpassed by the result of the analysis proposed by me.

The thickness of the stratum accessible to the dissolving action of the water may be taken as 20 centimetres at the bottom of the Wadi Rayan, and as 50 centimetres for the bed and sides of the canal, and the inundated lands which will be more thoroughly washed and undermined by the waves.

Categories of Desert Soils.—One can distinguish three categories of desert soils of Tertiary origin as far as their permeability is concerned, and also as to the ease with which the salt they contain can be dissolved.

1. Solid rocks; beds of limestone, of silicious and argillaceous limestone, and of calcareous sandstone.

2. Loose soils, composed of decomposed rocks, pebbles, boulders, shingle, etc.

3. Marly clays and sands, in layers overlying the plains, in the undulating slopes of the hills, and at the feet of bluffs.

To arrive methodically at the mean percentage of salt, it becomes necessary to make a quantitative chemical analysis of each of the three categories of soil separately, then measure their specific gravity, discover the thickness of the stratum which is permeable, and finally fix on the area. These are the necessary elements. The calculation which follows has no pretence to such precision.

Data more or less exact.—The following are the established or approximate facts which are at my disposal:—

1. Dimensions of the canal traversing the desert:—

Length	25 kilometres.
Breadth	40 metres.
Depth of water	9 metres.

2. Time of filling probably seven years.

3. Volume of water contained in the reservoir below R.L. + 27 metres = 18,600 millions of cubic metres.

4. Superficies of the water at R.L. 27 . . .650 millions of square metres.

5. Annual evaporation . . . 2 metres.

6. Salt contained in Nile water after Professor Sickenberger's analysis in 1883, 40 milligrams per litre = 40 grams per metre cube = $\frac{1}{250}$ per cent.*

(The Nile in summer has only $\frac{1}{2000}$ per cent. of salt.)

7. The mean specific gravity of salt, 2·25.

8. Solubility of salt in water, 1 : 2·75.

9. The specific gravity of the mean desert soils has been taken as practically the same as that of salt.

Estimate of Salt in the Wadi Rayan Reservoir.—The different sources from which salt can enter the proposed reservoir are enumerated in the following list:—

		Salt in the reservoir in millions of grams.
1. From the Nile in flood when the reservoir is full: 18,600 millions × 40	=	744,000
2. From the Nile in flood, to make good the losses from evaporation in seven years: 3000 millions of cubic metres × 40	=	120,000
3. The losses by evaporation in the canals during seven years	=	36,000
4. From the lands in the bed of the reservoir: 650 millions square metres × by $0{\cdot}2^{m}$ = 130 millions cubic metres (130,000,000 × 2·25) = 290 billions of grams, of which 2 per cent. amount to	=	5,800,000
5. From the bed and banks of the canal in the desert and the inundations: 2 per cent. of salt in a belt of 50 centimetres	=	650,000
6. From the Nile deposits composing the bed and banks of the canal in the Nile Valley, 20 kilometres long.		
7. From infiltrations and drainage into the same canal. .	=	150,000
Total		7,500,000

* According to Sickenberger, ordinary well water in Egypt, which is used for irrigation, contains $\frac{1}{12}$ per cent. of salt.

This equals 7,500,000 millions of grams, or 0·04 per cent.

The reservoir would therefore contain 7500 millions of kilograms of salt, or $\frac{1}{25}$ per cent. of salt; that is to say, half of the salt which exists in the water of those wells in Egypt which can be used for purposes of irrigation.

Substitution of Exact for Approximation Data.—Water containing a similar proportion of salt could be turned into the Nile without in any way compromising the agriculture. I again report that my calculation is based on maximum and assumed data. To obtain an exact calculation we must obtain exact data.

The Phenomenon of Sweet Water in the Karun Lake.—I conclude by calling attention to the extraordinary phenomenon of the water of Lake Karun in the Fayum being nearly sweet, in spite of the fact that it is the residuum of the ancient Lake Mœris. This question is intimately connected with that of the Wadi Rayan Reservoir. Very probably the creation of the depression of the Fayum, and the subsidence of the strata composing its bed, were due to the same geological action which produced the Wadi Rayan. This reflection makes it probable that this latter reservoir, when it is full, will disclose the same clefts and fissures in its bottom which I shall try and prove exist in the bed of the Karun Lake.

The Great Probability of Subterranean Drainage from the Wadi Rayan.—These subterranean passages will cause the loss of the great part of the water stored in the reservoir, and will give birth to distant springs, and probably even to the formation of new oases in the Libyan desert. The effect on the reservoir will be the following: the quantity of salt in the reservoir will be diminished, but the work of filling the reservoir will be more difficult and longer in operation.

The Karun Lake has to-day a surface of about 250 millions of square metres, and probably a cubic content of 1500 millions of cubic metres.

If we suppose that the lake has existed at this same level since the Roman period (A.D. 200), the lake would have received salt from the Nile since that period.

The salt contained in the Fayum Lake:—

		In millions of grams.
1. Salt in the entire mass of water, 1500 × 40 . . .	=	60,000
2. Salt contained in the strata of water evaporated annually during seventeen centuries, 2 × 250 × 40 × 1700 . .	=	34,000,000
Total		34,060,000

The salt in this case would amount to 34,060 millions of kilograms, *i.e.* 2·27 per cent.

As, however, at the time in question, the lake had very probably its water level at + 0, its volume has decreased by 43 metres in perpendicular height during the seventeen centuries. We must therefore find the quantity of salt in the water which was in excess of the present volume of the lake, and the annual loss by evaporation of the excess of the surface of the lake over the area of to-day. This latter excess equalled, in all probability, the present area of the lake.

At R.L. 0 the area of the lake was approximately 500 millions of square metres, and its excess volume was from thirteen to fourteen times the actual volume of to-day. I estimate this excess volume at 20,000 millions of cubic metres, and the salt at 800,000 millions of grams. The diminution of the surface of the lake was slightly under 250,000 square metres per annum. The salt contained in the strata

of water evaporated outside of the actual area of the lake to-day amounted in seventeen centuries to 17 billions of grams. The total quantity of 17,800,000 millions of grams of salt in 1500 millions of cubic metres of water gives a percentage of 1·186.

If we add 1·186 to 2·27 found before, we have 3·45 per cent. of salt in the lake to-day if it had existed only 1700 years, and at the beginning of that time, had been at level of the Mediterranean.

Other Sources of Salt in the Lake hitherto omitted.—So far I have not considered the supply of salt from other sources, such as—

1. The infiltration water brought into the lake by the canal, and drains from the cultivated land of the Fayum.

2. The greater quantity of salt in the Bahr Yusuf on entering the Fayum than in the Nile itself.

On the other hand, I have exaggerated in giving for the whole year the percentage of salt which is in the Nile only during flood.

Any way, one will readily see to what degree of concentration the salt ought to increase in a lake whose volume has been so considerably reduced through incalculable centuries. The vestiges of the ancient water surface which are to be found to the north of the lake at a distance of 8 kilometres from its present edge near the temple, discovered by me in 1884, and the other incontrovertible proofs of the existence of a Mœris in the sense of Herodotus, make it very probable that its level rose in ancient times to 22 or 23 metres above the Mediterranean.

The Quantity of Salt derived from Mœris.—According to Major Brown, the ancient Mœris had a surface of 1600 millions of square metres. Its volume may be calculated at 30,000 millions of cubic metres. This volume, reduced to 1500 millions cubic metres, brings the percentage of salt in the water of the actual lake to ·8 per cent. by itself, and the salt contained in the stratum evaporated during a single year being 128,000 millions of grams, ought in ten centuries to amount to 128,000 millions of kilograms. This would represent in the 1500 millions of cubic metres, of the lake of to-day, a percentage of 8·53.

8·5 *per cent. of Salt at least has disappeared in the Fayum Lake.*—But who knows since when the great lake existed, and how many centuries elapsed before the controlling of its water was begun? What has become of the salt which would have mounted to figures far higher than mine? Where, again, are the salts contained in the basin before the Nile water entered, and the salt of infiltration from drainage and irrigation? The salt in the lake to day bears no relation to the quantities I have enumerated.

To-day the waters of the Karun Lake are but slightly brackish. They are even potable, and inhabited by fresh-water fish from the Nile. It has been definitely proved that Lake Mœris never had a natural outlet towards the interior of the country, and that it never even was in connection with the Wadi Rayan, which it nearly touched. (See Major Brown's work on the Fayum, pages 43 and 48.) The Fayum basin is closed on all sides by bluffs and hills of considerable height. We have seen that, in spite of their concentration through immemorial ages, the salt in the waters of the lake has not increased. This renewal of fresh water can only be accounted for by subterranean drainage Where have the waters gone to?

(Lake Tchad, in the central Sudan, is an example of subterranean drainage on a larger scale. The waters are perfectly sweet, in spite of the absence of any

apparent outlet. The lake is drained by active infiltrations towards the N.E., in low depressions which are known as the Bahr el Ghazal.)

The Natron lakes are probably due to direct infiltrations from the Nile, since Sickenberger in 1892 observed that all the springs which gave birth to the lakes were situated on the eastern side of the valley. The difference of level, also, prevents the establishment of any similarity between the systems, as well as the fact that the springs of the Natron lakes are not thermal.

Oases and depressions provided with springs are to be found to the north-west of the Fayum as far as Siwa; and this latter oasis may perhaps obtain some of its water from the Karun Lake in spite of the difference of levels. There are many phenomena connected with thermal springs which as yet await solution. We are still in ignorance of the destination of the currents of those thermal springs which traverse the bottom of the depression of the great oases and the oasis of Dakhla, at great depths. These springs are abundant, and flow evidently towards the north. It is probable that all these subterranean streams, which are fed by the Nile, flow towards the Marmarica coast between Alexandria and Derna. There, owing to the tensile force inherent in all water at a high temperature, they are discharged at great depths below the level of the Mediterranean Sea.

(*Signed*) G. Schweinfurth.

APPENDIX IV.

Discharge Diagram of the Rosetta and Damietta Branches of the Nile below the Delta Barrages, 1887.

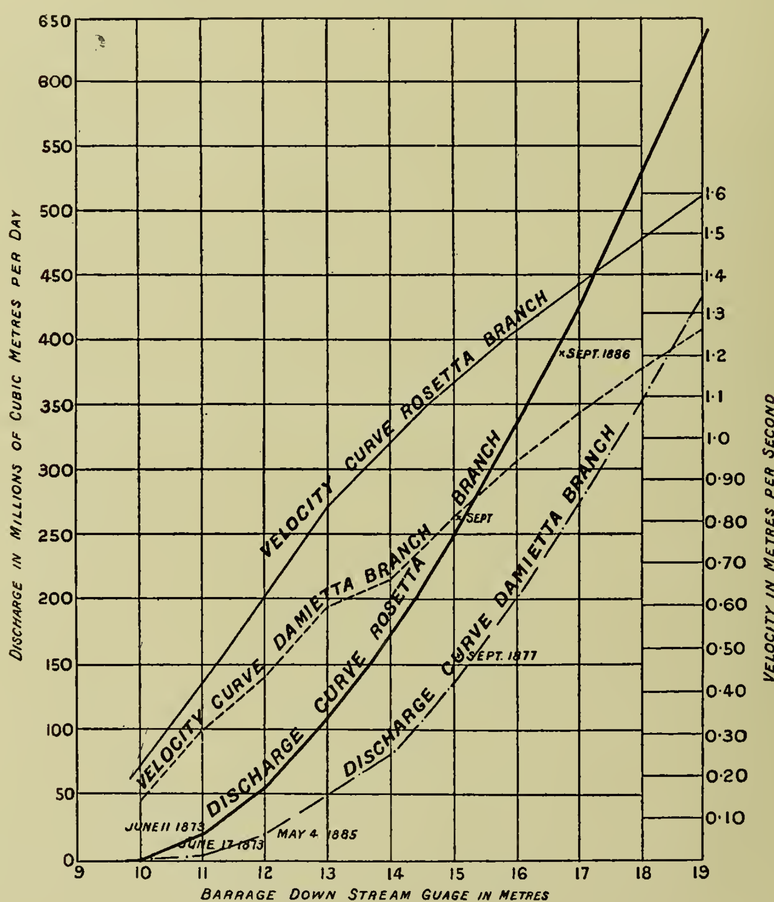


Fig. 188.

Calculated from slope and cross section, and verified by surface velocity observations by Colonel J. H. Western and Mr A. Reid, 1887.

APPENDIX V.

THE KOM OMBO ESTATE.

We give an account of the bold project for the cultivation of 30,000 acres of land north of Aswan, lying 24 metres above the summer supply of the Nile and 15 metres above high flood. The promoters applied for permission to use the water power of the Aswan dam for the irrigation of the estate; but meeting with no encouragement, they turned to coal. The following is a translation of a paper kindly written for us by Joseph Cattaui Pasha.

"In 1903 Sir Ernest Cassel and Messrs Suares Brothers & Co. conceived the idea of reclaiming the Kom Ombo plain, which extends from Gebel Silsila to Darau, north of Aswañ. 30,000 acres were purchased from the Government, with option to purchase the rest of the plain.

The plain lies at a level of 15 metres above the highest Nile floods, and its attempted cultivation was rendered possible by the great improvements in pumping plant. Coal has to be transported 1050 kilometres.

Three powerful high-pressure pumps were successively installed by the firm of Sulzer Brothers of Winterthur.

Each pump, operated by a triple-expansion engine of 1350 H.P., lifts 3 cubic metres (660 gallons) per second. The mean summer level of the Nile is R.L. 81·00 metres, and the flood R.L. 89·30 metres. The water is raised to R.L. 105·00 metres (or 24 metres in summer).

The three pumps lift between them 9 cubic metres per second, which is transported in three iron pipes, each 480 metres long and 2·00 metres diameter, with a mean velocity of 1 metre per second. The pipes discharge into a basin elevated well above the level of the ground, from which the water is carried in a steel semicircular flume, 6 metres wide, 4·5 metres deep, and 1700 metres long. Special provision has been made for expansion and contraction.

Of the total area of 30,000 acres, 24,000 have been levelled and provided with canals, regulators, roads, and villages. The main canal, called the Canal Cassel, is 24 kilometres long, and there are, in addition, 53 kilometres of secondary canals and 73 kilometres of tertiary canals, making 150 kilometres in all.

There are 40 villages with magazines, stables, and all necessaries, occupied by 20,000 people. The estate is provided with complete telephonic communication, and 85 kilometres of 60-centimetre railway.

There are 9 pairs of Fowler's ploughing engines, 620 head of cattle, and 16 thrashing machines in the hands of the Administration.

At the headquarters station at Kom Ombo are located central offices and magazines, a post office, police office, hotel, hospital, market, school, and mosque.

The principal crops are sugar-cane, wheat, barley, beans, and clover. Cotton is in an experimental stage.

During 1912–13 there were 4500 acres under sugar-cane, which provided cane for a central factory belonging to the Société Générale des Sucreries et de la Raffinerie d'Égypte. The factory can dispose of 100,000 tons of cane per season, and is ready to be doubled the moment the cane is forthcoming. Sugar-cane at Kom Ombo is rich in sugar, and is little exposed to frosts.

The capital expended on the works has been £1,000,000."

APPENDIX VI.

PREDICTION OF THE NILE SUPPLY.

We have retained this important subject to the end of the work, instead of inserting it in its proper place in paragraph 6, because it was still under investigation. Unfortunately, these investigations are still incomplete, and so this appendix must be less final than we had hoped.

Prediction of the supply of water in the river may be divided into: (1) prediction of the falling and low stages, that is, the winter and summer supplies; and (2) prediction of the flood. We deal with the former, at present the more precise, first.

(1) The water that finds its way down the Blue Nile is almost entirely due to the rainfall on the basin and not on the water surface itself. Great part of the rainfall evaporates again; part flows directly over the ground into tributary streams; and part sinks into the earth. Of the last, a considerable portion ultimately trickles into the river, and it is this chiefly which sustains the Abyssinian tributaries after 20th September, by which time rainfall on the main plateau is generally at an end. The soil, in short, acts as an enormous reservoir which is slowly emptied at a rate depending principally on the amount of water in it. The curve of deflux of the Blue Nile is therefore a function of the average height of the subsoil water in its upper basin, and is fairly regular from one year to another—would be quite regular but for the disturbance due to belated falls of rain. On the White Nile the amount of water stored in the soil is negligible; but, on the other hand, there are enormous accumulations in the Lakes, the Sudd region, the Pibor swamps, and the White Nile trough, all of which part with their stores at rates depending principally on the amount stored. In either case the conditions of the deflux are closely analogous. It is therefore a practicable problem, given the reading of any gauge at a date when steady infiltration and surface discharge are established and undisturbed, to calculate the course of the river until flood conditions prevail.

The flow into the river per unit of time is found to be approximately proportional to the height of the Blue Nile subsoil water, and to the surface accumulations of the White Nile—that is, to the quantity of water still available. We may write then $\frac{dQ}{dt} = -\alpha Q$, where Q is the total quantity available, t is the time, and α is a coefficient which is practically independent of t or Q. The solution of this equation gives $Q = Q_0 e^{-\alpha t}$, where Q_0 is the quantity available at the beginning of the time.

This equation suggests that the curve of deflux of the river will also obey an exponential law, and that the gauge readings (x) will satisfy some such equation as

$x - x_0 = A \cdot e^{-\beta t}$, where x_0, A, and β are constants for each gauge. The Nile at Wadi Halfa does, in point of fact, closely follow such an equation after the beginning of November, but it is found that the curve is fairly well represented by an equilateral hyperbola, which is simpler for purposes of calculation. An account of a method of prediction based on this fact will be found in *Cairo Scientific Journal*, vol. iii., 1909, p. 165.

We adopt, however, the following alternative method, which makes no other assumption than that the mean reading at the beginning of one month deviates from its normal by an amount proportional to the deviation at the beginning of a previous month. This assumption is true for small deviations, and is justified in practice for even considerable deviations.

From the assumption there results a linear equation $y = mx + c$, where y is the five-day mean at Wadi Halfa for the month in question, and x is that for the earlier month; m and c are constants that vary according to the pair of months selected. These have been determined from the five-day means for Wadi Halfa for each pair from November to June, and the resulting values are given in Table 279.

The third column for each month exhibits the coefficient of correlation, which is a measure of the extent to which the deviations of the variables are proportional. If the coefficient is zero, the variables are quite independent of each other; if it is $+1$, they vary together in direct proportion; if -1, they vary inversely. A coefficient of 0·3 means that there is probably a connection between the variables; one of 0·5 means that the connection is certain. The closeness of the connection naturally depends mainly on the nearness of the two months, but prediction from November even as far ahead as June can be made with a satisfactory amount of success. For the worst combination the correct sign of the deviation would be predicted in five cases out of six, and this six months ahead.

Two factors may contribute to give a failure of the prediction: unseasonable rain in the basin of the Blue Nile, or deviations of the White Nile from normal. If the Blue Nile has been raised above normal by late rains in October (the effect of which is very transient, seeing that the ground is then waterlogged), the result will be to forecast unnecessarily high readings for subsequent months. Again, rain sometimes falls in Abyssinia out of season late in the year or early in the spring. In this latter case the result is that more water reaches Wadi Halfa than has been foretold.

An example may make matters clear. On 1st to 5th November 1912 Wadi Halfa gauge read 3·81 metres; the prediction for 1st to 5th January is for a reading of $(3{\cdot}81 \times 0{\cdot}6406 - 0{\cdot}08)$, or 2·36 metres, and in about 96 per cent. of the cases there would be a deficiency as predicted. As a matter of fact, it was only 2·04 or 0·22 metres too low. The difference between forecast and reality was due to two long flushes that came down the Blue Nile in November and December.*

We suggest that the same method might be applied to Roseires or Kamlin gauge on the Blue Nile, and Malakal on the White Nile. We should then be in a

* Our prediction depends essentially on correspondence between the discharges at two stations, and would be on the whole more precise if gauge readings were always true indications of the discharge. On a sandy section, however, this is not so, and Wadi Halfa is unfortunately unsatisfactory in this respect. For this reason monthly soundings should be made on this and other important sections.

TABLE 279.—PREDICTION OF THE MEAN GAUGE READING AT WADI HALFA FOR THE FIRST PENTADE OF THE FOLLOWING MONTHS.

Predicted from	December 1–5.			January 1–5.			February 1–5.			March 1–5.		
	m.	*c.*	*r.*	*m.*	*c.*	*r.*	*m.*	*c.*	*r.*	*m.*	*c.*	*r.*
November 1–5 .	0·7207	+0·154	0·875	0·6406	−0·081	0·916	0·6471	−0·605	0·886	0·6138	−0·928	0·805
December 1–5 .	...	...	...	0·8149	+0·063	0·959	0·8130	−0·421	0·917	0·7828	−0·798	0·845
January 1–5 .	...	...	...	...	...	...	1·0304	−0·596	0·976	1·0168	−1·052	0·912
February 1–5 .	...	...	...	...	...	...	...	...	...	1·0127	−0·533	0·959

Predicted from	April 1–5.			May 1–5.			June 1–5.		
	m.	*c.*	*r.*	*m.*	*c.*	*r.*	*m.*	*c.*	*r.*
November 1–5 . .	0·5051	−0·812	0·722	0·3547	−0·339	0·688	0·3110	−0·138	0·674
December 1–5 . .	0·6476	−0·718	0·762	0·4615	−0·290	0·737	0·3708	+0·026	0·661
January 1–5 . .	0·8762	−1·042	0·858	0·6358	−0·570	0·807	0·5106	−0·202	0·726
February 1–5 . .	0·8760	−0·603	0·906	0·6446	−0·275	0·864	0·5061	+0·065	0·759
March 1–5 . .	0·8824	−0·179	0·963	0·6629	+0·007	0·938	0·5088	+0·312	0·806
April 1–5 . .	...	...	...	0·7409	+0·159	0·960	0·5335	+0·489	0·774
May 1–5 . .	...	...	...	...	...	...	0·7891	+0·276	0·884

position to say some twenty days ahead what change from the earliest forecasted reading at Wadi Halfa was likely to be necessary, and amend all the predictions accordingly. As regulation extends, the margin of uncertainty allowable will be narrowed, and this limitation will compel the employment of some systematic method of forecasting such as we have outlined here, and such as is in regular use in French hydrographic work.

(2) We come now to consider the possibility of forecasting the coming flood—a problem of much greater complexity, and therefore uncertainty, than the other. In paragraphs 5 and 6 we have sketched the meteorological conditions of the rainfall that feeds the Nile, and we have to-day a physical working hypothesis that we did not possess ten years ago. We cannot, however, afford to neglect any clues that may appear, even if we cannot at present see how they are to be fitted into that hypothesis.

The question of periodical recurrence in the floods has been frequently discussed, but hitherto on an empirical rather than a rigorous method. We have in hand an analysis of the maximum and minimum gauges at Roda for the 800 years from 640 A.D. which gives clear indications of the existence of such recurrences. More than this cannot be stated at present, as the work is still far from complete. One of the best known recurring phenomena is the appearance of sunspots with a period approximately 11·12 years. Mr B. H. Wade has found that there is a considerable resemblance between the curves for Nile floods and for sunspots, but with a two-year lag of the former on the latter. Prediction from the sunspot number would give the correct sign for the deviation of the flood in some two cases out of three.

In a lecture on *Lake Mœris* in January 1904, Sir William Willcocks spoke as follows:—

"It may be humiliating to make the confession, but from B.C. 2200 to the Arab invasion of Egypt in A.D. 640, while Lake Mœris performed its allotted task and the Nile possessed training works such as those we can see to-day in Nubia, Egypt was better protected from inundation, and the Nile better trained, than it is to-day. And yet we have many advantages which no Pharaoh possessed. By the aid of telegraphy we have knowledge of a coming flood a full fifteen days before it arrives in the Delta; the Khartoum gauge allows us to anticipate its very height. Meteorology is aiding us still further. In the paper I read at the Chicago International Exhibition it is stated that years of heavy rainfall in India are years of high flood in Egypt, while years of poor rainfall in India are years of low flood in Egypt. Sir John Eliot, the Director-General of the Meteorological Department of India, corrected this statement. He said that though this was not true of the Bengal monsoon, it was true of the Bombay monsoon. Years of heavy rainfall in Gujerat and Bombay are years of high flood on the Nile, and *vice versa*. As the rain falls in Bombay a month earlier than the Nile flood reaches Cairo, we have information of a high flood a month before it arrives, if we receive telegraphic information from Bombay. But we hope to go beyond this. I hope to establish that years of poor winter rainfall in the Levant and Mesopotamia, accompanied by weak khamsin winds in Egypt, foreshadow a poor flood ; while on the contrary, years of heavy winter rainfall in the Levant and Mesopotamia, accompanied by strong khamsin winds in Egypt, foreshadow a high flood. We have meteorological information about Beirut, Bagdad, Karachi, Bombay, Aden, Adis Ababa, Khartoum, Cairo, and scores of intermediate stations, and with the aid of these we may be able not only to anticipate a high flood by fifteen or thirty days but by sixty days, and so find our hands greatly strengthened in grappling with the dangers of an inundation."

This suggestion has been adversely criticised on the ground that there is no marked connection between southerly winds during April and May and the ensuing flood; but southerly winds are not necessarily khamsin winds, for there is an anti-cyclonic variety at this season. Still even so, there is a coefficient of correlation of about 0·3 between the two, which is at any rate a sufficient reason for more adequate investigation. As regards the connection between winter rainfall in the Levant and Mesopotamia, recent work in the Meteorological Service of India tends to indicate that conditions favourable to winter storms probably have an ultimate effect on the flood. This indication is therefore well worth further investigation.

Colonel Rawson's theory of a swing of the flood with a period of about nineteen years has been referred to on page 17; it is interesting to note that the analysis of readings above referred to indicates a period of about 19·2 years. According to this theory, the ten years from 1908 on should give a series of floods on the whole above normal, but so far the facts point to the contrary. It is difficult, however, to employ this theory directly for purposes of prediction, because the intervals indicated by Colonel Rawson are not regular, and we can never be certain that a given summer may not be the first of a new series.

Captain H. G. Lyons showed * that the negative correlation found by Sir John Eliot to hold between the monsoon rainfall of India and pressure there obtained also for Nile floods and pressure in North-East Africa, and one of us has shown that there is a negative correlation whose coefficient is − 0·3 between Abbassia pressure and the gauge readings at Aswan two months later. Prediction on the basis of this factor alone will be right in about two out of three cases.

Dr Gilbert Walker, F.R.S., has gone into the question with considerable detail.† He finds that the relative volume of the flood (f) is correlated with the following phenomena :—

(1) p, the pressure in South America for half of March, April, and May, in millimetres;

(2) z, the total rainfall at Zanzibar in April and May in inches;

(3) s, the accumulation of snow on the Himalayas in May on the scale in use in India; and

(4) p', pressure at Abbassia in May. In this case, however, the relationship is weak, and he rejects it in presence of the higher value for the other variables.

The correlations are exhibited in the following table :—

TABLE 280.—COEFFICIENT OF CORRELATION.

Elements.	Nile Flood. f.	Pressure, South America. p.	Rainfall, Zanzibar. z.	Snow Accumulation. s.
Nile flood	+ 1·00	+ 0·49	− 0·44	− 0·35
Pressure, South America	+ 0·49	+ 1·00	− 0·32	− 0·37
Rainfall, Zanzibar	− 0·44	− 0·32	+ 1·00	+ 0·31
Snow accumulation	− 0·35	− 0·37	+ 0·31	+ 1·00

* *Proceedings of the Royal Society*, A, lxxvi., 1905, p. 66.

† "Correlation of Seasonal Variations of Weather, ii.," *Indian Meteorological Memoirs*, 1910.

There is thus a considerable connection between the flood and pressure in South America, and one of us has shown that there is even a closer connection with pressure at St Helena. Dr Walker has found the following equation between the deviations of the variables :—

$$\Delta f = +4{\cdot}37\Delta p - 0{\cdot}55\Delta z - 1{\cdot}3\Delta s,$$

where Δ signifies deviation from normal.

The values of the independent variables are known early in June, when a forecast of the coming flood may be made with about 80 per cent. of success. Investigations are proceeding in both India and Egypt, and there is no doubt that this equation will shortly be improved on. For the present, however, until pressure at St Helena is substituted for that in South America, and the effects of the other factors mentioned are worked into a numerical equation, this equation of Dr Walker's must form the basis for flood prediction.

An attempt is being made in the Meteorological Section of the Survey Department to give definite forecasts of Aswan gauge for 15th, 22nd, and 28th August, the critical dates laid down by Colonel Ross (see page 324), to assist the Irrigation Department in deciding whether the coming flood is likely to be a poor one or not. Up to the present the prediction cannot be said to be of much more use than to give a warning, but it will shortly be improved, and it will then be possible to forecast the reading of Aswan gauge some four weeks ahead, and make preparations for the routine of an abnormally high or low flood.

APPENDIX VII.

THE NILE IN 1913.

THE position we have consistently taken up in this book may be thus summarised:—

(1) The utilisation in the past of a very substantial part of the water stored in the Aswan Reservoir for anticipating the flood has done more harm than good to the country (pages 412 and 748).

(2) In regulating on the Aswan dam, all the water of the reservoir sent down on a falling or stationary gauge has reached its destination; when sent down on a rising gauge (fig. 185), all the water needed to fill the trough of the Nile has been thrown away. This loss has amounted to 400,000,000 cubic metres per annum, or two-fifths of the capacity of the lower reservoir (pages 749 and 750).

(3) This enormous loss of water has not been realised, because it has been more than made good by the extra supply of about 200 cubic metres per second sent down by the Albert Nile, owing to the removal of the sudds and the dredging works of recent years. A maximum discharge of 200 cubic metres per second spread over 100 days means 1,150,000,000 cubic metres at least, or as much as the contents of the lower Aswan Reservoir (pages 253, 268, 405, 705, 707, and 749).

(4) The storage capacity of the Aswan Reservoir is appreciably increased by the fact that the water brought down by the freshets of the Blue Nile and the Atbara has been stored in the reservoir and utilised at will (page 214). This was shown very clearly indeed during the summer of 1913 (see Table 282).

(5) The seepage into the river is very considerable and is an important asset of the country. Every additional acre of land perennially irrigated in Upper Egypt adds its quota to this seepage water (pages 83, 381, 387, 388, 406, 407, 429, 430, 705, 706, 749, 750). It amounts to some 100 cubic metres per second in April, 90 in May, 80 in June, and 40 in July, in excess of all losses by evaporation, etc. The total quantity amounts to just over 1,000,000,000 cubic metres, or the contents of the lower reservoir at Aswan.

To the above we may add:—

(6) The Nubian sandstone is very porous indeed (see Appendix II.), and the water which soaks into the rocks between November and April is given back to the reservoir between May and July. This asset in all probability neutralises the losses by evaporation.

With this preface we shall describe the low summer of 1913.

Table 282, which gives the gauge at Wadi Halfa for 1912 and 1913, shows that the summer supply of the river was well maintained in 1913 up to the 5th July, but fell away after that date. Table 281 gives the discharges of the river at Wadi Halfa and the seepage additions in Egypt. The two together give the

total naturally supplied. The next column gives the summer requirements of Egypt on liberal lines from Table 242, and is followed by a column showing the balance needed to be made good by the Aswan Reservoir. We calculate that the total quantity needed to be supplied by the reservoir was 1½ milliards of cubic metres, to meet which it held 2,300,000,000 cubic metres, or a surplus of 800,000,000 cubic metres.

TABLE 281.—DISCHARGES, WADI HALFA, 1913.

Date.	Discharge in cubic metres per second.					Discharge required, in millions of cubic metres per day.	Multiply by, for Number of Days.	Total Quantity of Water needed from Reservoir, in millions of cubic metres.
	In River at Wadi Halfa.	Seepage added in Egypt.	Total naturally available.	Summer Require-ments from Table 242.	Quantity to be made good by the Reservoir.			
April .	510	100	610	760	150	17·4	30	522
May .	470	90	560	630	70	8·1	31	251
June .	590	80	670	750	80	9·3	30	279
July 1–25	610	40	650	750	100	11·6	40*	464
25–31	1190	...	1190	750	...	Total .	.	1,516

* 40=25 days + 15 days from Wadi Halfa to the Delta Barrage.

If we compare the curves at Aswan for 1910 (a typical year when a great part of the reservoir water was utilised for anticipating the flood) with that for 1913 (when the reservoir water was utilised for maintaining the summer supply), we see how little water was wasted proportionally in the latter year in filling the trough of the Nile, up to the 10th of July. The summer irrigation of 1913 has taught us that the Aswan Reservoir, if utilised for aiding the summer supply for which it was created, is twice as effective as it has been in all past years when it was used in great part, euphemistically for anticipating the flood, but in reality for filling the trough of the Nile between Aswan and Cairo (see pages 749 and 750).

Owing to the flood being very late and very low, and practically no effort having been made to anticipate it, the cotton yield of 1913 should be very high; and, if there is no severe visitation of boll worm, we may go far towards realising a harvest of ten million kantars as prophesied in the lecture on *The Ten-Million Kantar Cotton Crop* (see pages 411–414).

The flood so far is abnormally low, and unless it improves considerably before the 15th September there will be great distress over large areas of Upper Egypt. We have advocated the utilisation of the water power of the Aswan dam for the amelioration of the condition of the most unfortunate of these tracts (page 751), and the provision of massive pitching downstream of the Assiut and Esna Barrages to enable them to hold up, without danger, two metres of water in flood (pages 663 and 673).

Table 283 gives the gauge of the Blue Nile at Roseires for a series of years, while Table 284 gives the gauges on the Upper and Lower Nile for 1913. Plate LXXXI. shows clearly the extraordinary low flood, as distinct from the low summer, of 1913 up to the end of August.

TABLE 282.—WADI HALFA LOW SUMMER GAUGES.

Date.		1890.	1900.	1912.	1913.	
January	1– 5	2·71	1·88	3·01	2·58	
	6–10	2·65	1·79	2·93	2·49	
	11–15	2·59	1·69	2·83	2·44	
	16–20	2·52	1·63	2·72	2·38	
	21–25	2·40	1·57	2·59	2·30	
	26–31	2·25	1·51	2·47	2·18	
February	1– 5	2·03	1·44	2·35	2·04	
	6–10	1·90	1·40	2·25	1·95	
	11–15	1·76	1·36	2·16	1·85	
	16–20	1·67	1·34	2·07	1·76	Winter.
	21–25	1·54	1·30	1·96	1·69	
	26–end	1·46	1·30	1·89	1·63	
March	1– 5	1·38	1·23	1·80	1·55	
	6–10	1·35	1·18	1·68	1·47	
	11–15	1·29	1·11	1·63	1·48	
	16–20	1·20	1·06	1·61	1·42	
	21–25	1·16	1·06	1·57	1·34	
	26–31	1·11	1·00	1·52	1·35	
April	1– 5	1·02	0·96	1·47	1·34	
	6–10	0·93	0·97	1·39	1·31	
	11–15	0·85	0·95	1·34	1·30	
	16–20	0·80	0·95	1·29	1·23	
	21–25	0·76	0·97	1·28	1·15	
	26–30	0·70	0·97	1·24	1·14	
May	1– 5	0·64	0·98	1·22	1·14	
	6–10	0·62	0·90	1·15	1·14	
	11–15	0·62	0·95	1·13	1·08	
	16–20	0·63	0·94	1·14	1·10	
	21–25	0·64	0·95	1·11	1·16	
	26–31	0·65	1·08	1·06	1·20	Summer.
June	1– 5	0·71	1·06	1·00	1·30	
	6–10	0·82	1·17	0·99	1·39	
	11–15	0·93	1·33	1·03	1·42	
	16–20	1·15	1·42	1·04	1·46	
	21–25	1·37	1·52	1·08	1·50	
	26–30	1·47	1·58	1·15	1·47	
July	1– 5	2·19	1·65	1·29	1·49	
	6–10	2·54	2·07	1·71	1·45	
	11–15	2·91	2·63	2·30	1·47	
	16–20	3·32	3·18	2·88	1·36	
	21–25	3·94	3·43	3·15	1·50	
	26–31	5·91	3·86	3·69	2·40	
August	1– 5	6·64	5·62	5·55	2·75	
	6–10	7·30	7·30	6·55	2·88	
	11–15	8·02	7·76	7·03	3·29	
	16–20	8·28	**8·01**	**7·55**	4·06	Flood.
	21–25	8·65	7·98	7·42	4·78	
	26–31	8·73	8·00	7·44	5·46	
September	1– 5	**8·74**	7·74	7·42	5·75	

TABLE 283.—ROSEIRES GAUGE.

Date.		1907.	1908.	1909.	1911.	1912.	1913.	Mean. 1905–12.
January	1– 5	12·23	11·93	12·50	12·80	12·52	12·02	12·42
	6–10	12·13	11·83	12·42	12·62	12·41	11·98	12·30
	11–15	12·04	11·71	12·31	12·50	12·34	11·88	12·19
	16–20	11·94	11·64	12·23	12·42	12·26	11·79	12·10
	21–25	11·87	11·57	12·18	12·30	12·15	11·70	12·02
	26–31	11·79	11·57	12·10	12·16	12·08	11·61	11·93
February	1– 5	11·72	11·57	11·95	12·07	12·08	11·53	11·87
	6–10	11·65	11·47	11·85	12·00	11·97	11·50	11·80
	11–15	11·59	11·36	11·78	11·92	11·86	11·50	11·75
	16–20	11·55	11·32	11·71	11·84	11·78	11·50	11·70
	21–25	11·50	11·32	11·64	11·76	11·71	11·42	11·66
	26–end	11·46	11·25	11·59	11·70	11·68	11·36	11·63
March	1– 5	11·46	11·17	11·54	11·67	11·63	11·38	11·57
	6–10	11·47	11·12	11·48	11·67	11·54	11·30	11·51
	11–15	11·32	11·08	11·42	11·68	11·44	11·21	11·45
	16–20	11·24	11·06	11·39	11·62	11·33	11·16	11·42
	21–25	11·18	11·05	11·36	11·52	11·29	11·10	11·41
	26–31	11·17	11·00	11·42	11·49	11·22	11·04	11·40
April	1– 5	11·21	10·98	11·62	11·45	11·18	11·02	11·39
	6–10	11·21	11·13	11·87	11·45	11·17	11·09	11·38
	11–15	11·44	10·99	12·07	11·45	11·17	11·09	11·39
	16–20	11·66	10·92	11·86	11·42	11·14	11·10	11·40
	21–25	11·52	10·87	11·64	11·38	11·06	11·16	11·41
	26–30	11·38	10·94	12·33	11·32	11·04	11·59	11·42
May	1– 5	11·28	11·21	12·16	11·80	11·04	11·51	11·47
	6–10	11·08	11·53	12·09	12·00	11·03	11·96	11·51
	11–15	10·96	11·26	11·84	12·48	11·03	12·03	11·55
	16–20	10·95	11·05	12·10	13·08	11·03	11·83	11·63
	21–25	11·44	10·98	13·14	12·28	11·05	11·86	11·83
	26–31	11·57	11·21	13·43	12·04	11·49	11·82	12·01
June	1– 5	11·74	11·42	13·69	12·10	11·48	11·65	12·03
	6–10	12·47	11·86	13·60	12·33	12·03	11·57	12·36
	11–15	12·56	12·48	14·01	12·98	12·70	11·25	12·77
	16–20	12·72	13·25	14·11	13·14	13·49	11·11	13·16
	21–25	12·74	13·20	14·47	13·34	13·45	11·20	13·30
	26–30	13·20	13·03	14·31	13·68	14·06	12·15	13·43

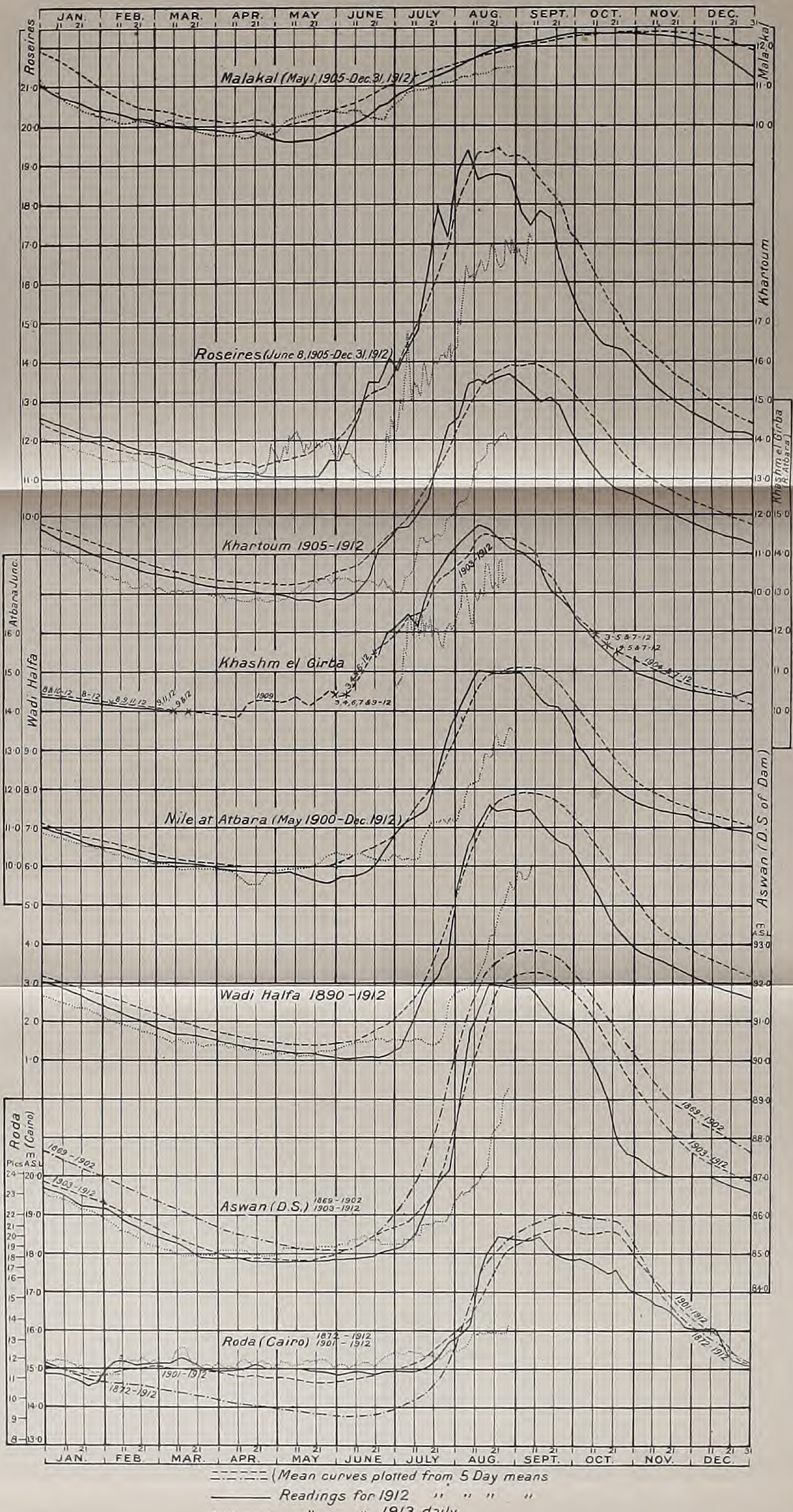
TABLE 283.—ROSEIRES GAUGE (*continued*).

Date.		1907.	1908.	1909.	1911.	1912.	1913.	Mean.
July	1– 5	13·93	13·33	14·69	14·22	13·72	12·60	13·89
	6–10	14·36	14·38	14·85	15·00	14·38	13·72	14·52
	11–15	14·90	15·23	16·07	15·43	14·80	13·34	15·09
	16–20	14·73	15·86	16·55	15·55	16·22	13·63	15·59
	21–25	15·02	16·21	17·09	16·04	17·96	14·06	16·17
	26–31	15·43	17·32	18·07	17·13	17·15	14·25*	16·93
August	1– 5	16·24	19·72	19·33	17·27	18·86	14·79*	18·09
	6–10	16·59	20·57	19·19	18·06	19·41	16·19*	18·75
	11–15	17·20	22·11	19·90	19·62	18·66	16·43*	19·32
	16–20	17·36	20·91	20·43	20·31	18·73	16·66	19·37
	21–25	18·79	20·14	19·54	20·32	18·78	16·51	19·43
	26–31	17·49	20·43	20·40	19·20	18·70	16·91	19·35
September	1– 5	17·75	20·39	19·80	19·52	17·80	16·74	
	6–10	17·86	20·20	19·36	19·55	17·46		
	11–15	18·02	19·14	18·76	19·32	17·82		
	16–20	17·38	18·78	18·76	18·66	17·67		
	21–25	16·92	18·97	19·38	17·78	16·63		
	26–30	15·81	18·93	18·52	17·18	15·93		
October	1– 5	15·36	19·14	18·02	17·04	15·31		
	6–10	15·16	16·20	17·58	17·03	14·88		
	11–15	15·23	16·89	17·18	16·19	14·53		
	16–20	14·78	16·24	16·25	15·54	14·39		
	21–25	14·71	15·78	15·70	15·23	14·31		
	26–31	14·31	15·27	15·18	15·03	14·02		
November	1– 5	13·90	14·94	14·77	15·03	13·74		
	6–10	13·70	14·72	14·57	14·78	13·47		
	11–15	13·40	14·53	14·30	14·32	13·25		
	16–20	13·18	14·26	14·04	14·00	13·07		
	21–25	13·03	14·07	13·85	13·73	12·92		
	26–30	12·90	13·80	13·72	13·58	12·75		
December	1– 5	12·65	13·55	13·49	13·50	12·59		
	6–10	12·51	13·40	13·29	13·40	12·45		
	11–15	12·43	13·23	13·14	13·15	12·31		
	16–20	12·23	13·06	13·01	12·98	12·19		
	21–25	12·12	12·87	12·87	12·80	12·19		
	26–31	12·00	12·67	12·77	12·65	12·14		
Year .	Mean *	...	...	...	14·11	13·54		
	Max. †	...	...	...	21·00	19·90		
	Min. ‡	...	...	...	11·31	11·03		
	Range	...	...	...	9·69	8·87		

* Mean derived from daily readings. † Highest reading recorded in year.
‡ Lowest reading recorded in year.

TABLE 284.—NILE GAUGES, 1913.

Date.		Malakal.	Roseires.	Khashm el Girba.	Wadi Halfa.	Aswan R.L.	Delta Barrage (Upstream) R.L.	
January	1– 5	11·08	12·03	...	2·58	86·49	14·27	
	6–10	10·94	11·98	...	2·49	86·41	14·35	
	11–15	10·75	11·88	...	2·44	86·32	14·34	
	16–20	10·62	11·77	...	2·38	86·18	14·25	
	21–25	10·48	11·70	...	2·30	86·08	14·21	
	26–31	10·37	11·60	...	2·18	85·96	14·18	
February	1– 5	10·27	11·52	...	2·04	85·79	14·20	
	6–10	10·20	11·48	...	1·95	85·60	14·47	
	11–15	10·17	11·50	...	1·85	85·48	14·78	Winter.
	16–20	10·21	11·50	...	1·76	85·36	14·80	
	21–25	10·18	11·42	...	1·69	85·21	14·80	
	26–28	10·14	11·36	...	1·63	85·12	14·80	
March	1– 5	10·13	11·38	...	1·55	85·05	14·80	
	6–10	10·21	11·30	...	1·47	84·98	14·91	
	11–15	10·14	11·21	...	1·48	84·91	15·17	
	16–20	10·03	11·16	...	1·42	84·90	14·84	
	21–25	9·94	11·10	...	1·34	84·90	14·75	
	26–31	9·84	11·04	...	1·35	84·92	14·75	
April	1– 5	9·80	11·03	...	1·34	85·01	14·72	
	6–10	9·81	11·09	...	1·31	85·01	14·71	
	11–15	9·78	11·09	...	1·30	85·01	14·83	
	16–20	9·76	11·10	...	1·23	84·90	14·76	
	21–25	9·86	11·17	...	1·15	84·90	14·85	
	26–30	9·85	11·60	...	1·14	84·90	14·72	
May	1– 5	9·94	11·52	...	1·14	84·98	14·79	
	6–10	10·17	11·96	...	1·14	85·10	14·76	
	11–15	10·26	12·05	...	1·08	85·10	14·74	
	16–20	10·37	11·83	...	1·10	85·10	14·83	
	21–25	10·42	11·85	...	1·16	85·14	14·84	
	26–31	10·44	11·82	...	1·20	85·15	14·76	Summer.
June	1– 5	10·40	11·67	...	1·30	85·19	14·75	
	6–10	10·44	11·56	...	1·39	85·26	14·71	
	11–15	10·42	11·25	...	1·42	85·34	14·79	
	16–20	10·28	11·11	...	1·46	85·32	14·78	
	21–25	10·26	11·20	...	1·50	85·26	14·82	
	26–30	10·41	12·15	...	1·47	85·20	15·01	
July	1– 5	10·69	12·56	...	1·49	85·20	15·03	
	6–10	10·85	13·72	...	1·45	85·30	15·05	
	11–15	10·96	13·34	...	1·47	85·46	15·00	
	16–20	11·01	13·63	12·07	1·36	85·70	14·98	
	21–25	11·09	14·06	11·85	1·50	85·78	14·91	
	26–31	11·17	14·25	11·96	2·40	85·98	15·07	
August	1– 5	11·26	14·79	12·58	2·75	86·47	15·13	
	6–10	11·32	16·19	12·74	2·88	86·61	15·34	
	11–15	11·36	16·43	12·99	3·29	86·90	15·50	
	16–20	11·41	16·66	13·50	4·06	88·59		Flood.
	21–25	11·45	16·51	13·02	4·78	88·42		
	26–31	11·49	16·91	...	5·46			
September	1– 5	...	16·74	...	5·75			


Malakal (May 1, 1905-Dec. 31, 1912)
Roseires (June 8, 1905-Dec. 31, 1912)
Khartoum 1905-1912
Khashm el Girba
Nile at Atbara (May 1900-Dec. 1912)
Wadi Halfa 1890-1912
Aswan (D.S.) 1869-1902 1903-1912
Roda (Cairo) 1872-1912 1901-1912
Roseires
Malakal
Khartoum
Khashm el Girba (R. Atbara)
Atbara Junc.
Wadi Halfa
Aswan (D.S. of Dam)
Roda (Cairo)
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
(Mean curves plotted from 5 Day means
Readings for 1912 " " " "
" " 1913 daily

APPENDIX VIII.

TABLE 285.—CONVERTING CUBIC METRES PER SECOND INTO CUBIC METRES PER DAY.

Cubic metres per second.	Cubic metres per day.	Cubic metres per second.	Cubic metres per day.	Cubic metres per second.	Cubic metres per day.	Cubic metres per second.	Cubic metres per day.
1	86,400	26	2,246,400	51	4,406,400	76	6,566,400
2	172,800	27	2,332,800	52	4,492,800	77	6,652,800
3	259,200	28	2,419,200	53	4,579,200	78	6,739,200
4	345,600	29	2,505,600	54	4,665,600	79	6,825,600
5	432,000	30	2,592,000	55	4,752,000	80	6,912,000
6	518,400	31	2,678,400	56	4,838,400	81	6,998,400
7	604,800	32	2,764,800	57	4,924,800	82	7,084,800
8	691,200	33	2,851,200	58	5,011,200	83	7,171,200
9	777,600	34	2,937,600	59	5,097,600	84	7,257,600
10	864,000	35	3,024,000	60	5,184,000	85	7,344,000
11	950,400	36	3,110,400	61	5,270,400	86	7,430,400
12	1,036,800	37	3,196,800	62	5,356,800	87	7,516,800
13	1,123,200	38	3,283,200	63	5,443,200	88	7,603,200
14	1,209,600	39	3,369,600	64	5,529,600	89	7,689,600
15	1,296,000	40	3,456,000	65	5,616,000	90	7,776,000
16	1,382,400	41	3,542,400	66	5,702,400	91	7,862,400
17	1,468,800	42	3,628,800	67	5,788,800	92	7,948,800
18	1,555,200	43	3,715,200	68	5,875,200	93	8,035,200
19	1,641,600	44	3,801,600	69	5,961,600	94	8,121,600
20	1,728,000	45	3,888,000	70	6,048,000	95	8,208,000
21	1,814,400	46	3,974,400	71	6,134,400	96	8,294,400
22	1,900,800	47	4,060,800	72	6,220,800	97	8,380,800
23	1,987,200	48	4,147,200	73	6,307,200	98	8,467,200
24	2,073,500	49	4,233,600	74	6,393,600	99	8,553,600
25	2,160,000	50	4,320,000	75	6,480,000	100	8,640,000

Rule for Mental Calculations.—To pass from cubic metres per second to millions of cubic metres per day, *divide* by 12. If greater accuracy is wanted, *add* then 4 per cent.

TABLE 286.—CONVERTING CUBIC METRES PER DAY INTO CUBIC METRES PER SECOND.

Cubic metres per 24 hours. Millions	Cubic metres per second.	Cubic metres per 24 hours. Millions	Cubic metres per second.	Cubic metres per 24 hours. Millions	Cubic metres per second.	Cubic metres per 24 hours. Millions	Cubic metres per second.	Cubic metres per 24 hours. Millions	Cubic metres per second.
0·00	...	2·00	23·1481	4·00	46·2963	6·00	69·4444	8·00	92·5926
·05	0·5787	·05	23·7268	·05	46·8750	·05	70·0231	·05	93·1713
·10	1·1574	·10	24·3055	·10	47·4537	·10	70·6018	·10	93·7500
·15	1·7361	·15	24·8842	·15	48·0324	·15	71·1805	·15	94·3287
·20	2·3148	·20	25·4629	·20	48·6111	·20	71·7592	·20	94·9074
·25	2·8935	·25	26·0417	·25	49·1828	·25	72·3380	·25	95·4861
·30	3·4722	·30	26·6203	·30	49·7685	·30	72·9166	·30	96·0648
·35	4·0509	·35	27·1990	·35	50·3472	·35	73·5053	·35	96·6436
·40	4·6296	·40	27·7777	·40	50·9259	·40	74·0740	·40	97·2222
·45	5·2083	·45	28·3564	·45	51·5046	·45	74·6527	·45	97·8009
0·50	5·7870	2·50	28·9352	4·50	52·0833	6·50	75·2315	8·50	98·3796
·55	6·3657	·55	29·5338	·55	52·6620	·55	75·8101	·55	98·9583
·60	6·9444	·60	30·0925	·60	53·2407	·60	76·3888	·60	99·5370
·65	7·5231	·65	30·6712	·65	53·8194	·65	76·9675	·65	100·1157
·70	8·1018	·70	31·2499	·70	54·3981	·70	77·5462	·70	100·6944
·75	8·6805	·75	31·8287	·75	54·9768	·75	78·1250	·75	101·2731
·80	9·2593	·80	32·4074	·80	55·5556	·80	78·7037	·80	101·8519
·85	9·8380	·85	32·9861	·85	56·1343	·85	79·2824	·85	102·4306
·90	10·4167	·90	33·5648	·90	56·7130	·90	79·8611	·90	103·0093
·95	10·9954	·95	34·1335	·95	57·2917	·95	80·4398	·95	103·5880
1·00	11·5741	3·00	34·7222	5·00	57·8704	7·00	81·0185	9·00	104·1667
·05	12·1527	·05	35·3009	·05	58·4491	·05	81·5972	·05	104·7454
·10	12·7314	·10	35·8796	·10	59·0278	·10	82·1759	·10	105·3241
·15	13·3101	·15	36·4583	·15	59·6065	·15	82·7546	·15	105·9028
·20	13·8888	·20	37·0370	·20	60·1852	·20	83·3333	·20	106·4815
·25	14·4676	·25	37·6127	·25	60·7639	·25	83·9120	·25	107·0602
·30	15·0462	·30	38·1944	·30	61·3426	·30	84·4907	·30	107·6389
·35	15·6249	·35	38·7731	·35	61·9213	·35	85·0694	·35	108·2276
·40	16·2036	·40	39·3518	·40	62·5000	·40	85·6481	·40	108·8063
·45	16·7823	·45	39·9305	·45	63·0787	·45	86·2268	·45	109·3750
1·50	17·3611	3·50	40·5092	5·50	63·6574	7·50	86·8055	9·50	109·9537
·55	17·9398	·55	41·0879	·55	64·2361	·55	87·3842	·55	110·5324
·60	18·5196	·60	41·6660	·60	64·8148	·60	87·9629	·60	111·1111
·65	19·0977	·65	42·2453	·65	65·3935	·65	88·5416	·65	111·6898
·70	19·6759	·70	42·8240	·70	65·9712	·70	89·1203	·70	112·2685
·75	20·2546	·75	43·4028	·75	66·5509	·75	89·6991	·75	112·8472
·80	20·8334	·80	43·9815	·80	67·1297	·80	90·2778	·80	113·4260
·85	21·4121	·85	44·5602	·85	67·7084	·85	90·8565	·85	114·0047
·90	21·9908	·90	45·1389	·90	68·2871	·90	91·4352	·90	114·5834
·95	22·5695	·95	45·7175	·95	68·8658	·95	92·0139	·95	115·1623

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